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# AN ASSESSMENT OF MINING IMPACTS ON WATER QUALITY IN THE NORTHERN BOULDER BATHOLITH

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Prepared for:

Statewide Section 208
Water Quality Management Planning
Land Use/Water Quality Relationships

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# ABSTRACT

Investigations of the Boulder River from Basin to Boulder, Ten Mile Creek, Little Blackfoot River, and Prickly Pear Creek drainages were conducted from April through September, 1977. Existing degraded water quality resulting from acid mine wastes and reclamation necessary to alleviate water quality problems were determined. The major problems in the Boulder River drainage are acid, metals, and sediment from the Crystal Mine on Uncle Sam Gulch and the Comet Mine on High Ore Creek. Mines in and near Rimini, and Upper Minnehaha Creek are the greatest pollutant contributors to the Ten Mile Creek drainage. Lily-Orphan Boy Mine has a great impact on Telegraph Creek in the Little Blackfoot drainage. Spring Creek contributes a tremendous load of acid, sediment, and metals to Prickly Pear Creek. Clancy Creek (a tributary to Prickly Pear Creek) is affected by mine waste in its upper reaches. Reclamation efforts should be directed towards these streams to (1) reduce metal loading, (2) raise and stabilize the pH, and (3) prevent sedimentation. In order to effectively control and abate present and future pollution problems to state waters, miners will need professional assistance in designing proper facilities for handling wastes.

## TABLE OF CONTENTS

Page

INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . . . 1

MINING PROBLEMS . . . . . . . . . . . . . . . . . . . . . . 5

- Acid Mine Drainage . . . . . . . . . . . . . . . . . . . . 5
- Heavy Metals . . . . . . . . . . . . . . . . . . . . . . . 6
- Sedimentation . . . . . . . . . . . . . . . . . . . . . . 6

ABATEMENT . . . . . . . . . . . . . . . . . . . . . . . . . 8

- PHYSICAL METHODS . . . . . . . . . . . . . . . . . . . . . 8
- CHEMICAL METHODS . . . . . . . . . . . . . . . . . . . . . 10

TASKS . . . . . . . . . . . . . . . . . . . . . . . . . . . 12

RESULTS . . . . . . . . . . . . . . . . . . . . . . . . . . 13

- BOULDER RIVER DRAINAGE . . . . . . . . . . . . . . . . . . 15
  - Field Observations . . . . . . . . . . . . . . . . . . 17
- PRICKLY PEAR CREEK DRAINAGE . . . . . . . . . . . . . . . 19
  - Field Observations . . . . . . . . . . . . . . . . . . 21
- TEN MILE CREEK DRAINAGE . . . . . . . . . . . . . . . . . 29
  - Field Observations . . . . . . . . . . . . . . . . . . 31
- LITTLE BLACKFOOT RIVER DRAINAGE . . . . . . . . . . . . . 37
  - Field Observations . . . . . . . . . . . . . . . . . . 39

CONCLUSIONS . . . . . . . . . . . . . . . . . . . . . . . . 44

- BOULDER RIVER DRAINAGE . . . . . . . . . . . . . . . . . . 44
- PRICKLY PEAR CREEK DRAINAGE . . . . . . . . . . . . . . . 45
- TEN MILE CREEK DRAINAGE . . . . . . . . . . . . . . . . . 46
- LITTLE BLACKFOOT RIVER DRAINAGE . . . . . . . . . . . . . 47

DISCUSSION AND RECOMMENDATIONS . . . . . . . . . . . . . . . 48

REFERENCES . . . . . . . . . . . . . . . . . . . . . . . . . 52

APPENDICES . . . . . . . . . . . . . . . . . . . . . . . . . 54

## LIST OF FIGURES

Page

Figure 1. Index Map Showing Location and Structural Setting of the Boulder Batholith . . . . . . . 2

Figure 2. Northern Boulder Batholith Study Area . . . . 3

Figure 3. The Boulder River Drainage . . . . . . . . . . . 16

Figure 4. The Prickly Pear Creek Drainage . . . . . . . 20

Figure 5. The Ten Mile Creek Drainage . . . . . . . . . 30

Figure 6. The Little Blackfoot River Drainage . . . . . 38

## LIST OF TABLES

Table 1. Recommended Limits for Certain Toxic Elements . . . . . . . . . . . . . . . . . . . . 13

# INTRODUCTION

In 1899, W. H. Weed gave the name Boulder Batholith to a granitic body about 70 miles long and 35 miles wide, extending from near Helena to south of Butte (Figure 1). The bulk of the batholith was formed about 72 million years ago during Lake Cretaceous Time. The batholith consists primarily of quartz monzonite and grandorite, closely related rocks consisting primarily of silica (60-70%).

The northern part of the Boulder Batholith is bordered on the north by Ten Mile Creek, on the east by Prickly Pear Creek, on the south by the Boulder River, and on the west by the Little Blackfoot River and Basin Creek (Figure 2). This has been an area of intense mining activity for many years. Miners searched primarily for gold, leaving behind ores laden with zinc, copper, silver, lead, and other metals.

Surface and underground mining are the two practices used in the area. Underground mining consists of digging a tunnel into rock in order to remove the ore. Surface mining consists mostly of placer mining, which involves the washing of mineral deposits. Placer mining ranges from a single miner panning for gold to large dredges like those operating on Prickly Pear Creek.

Miners were so involved with "striking it rich", that most of them did not foresee the pollution problems resulting from their operations. When mining subsided some 30 or 40 years ago, pollution of streams remained. The effect of acid, heavy metals, and sediment on receiving waters continued for many years.

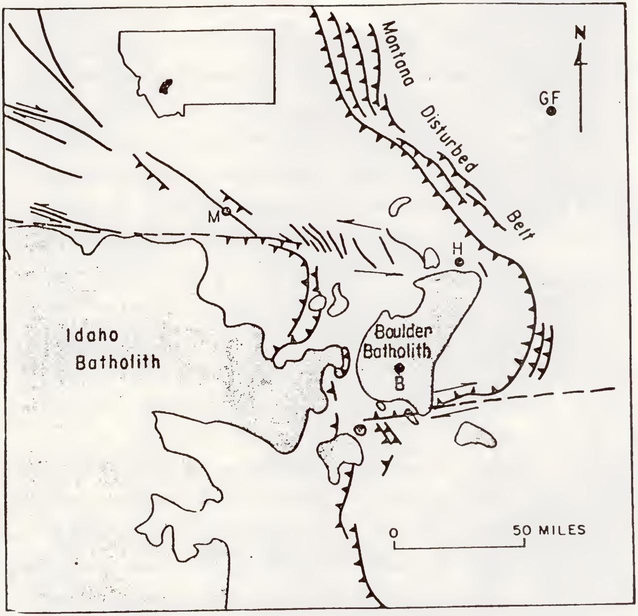
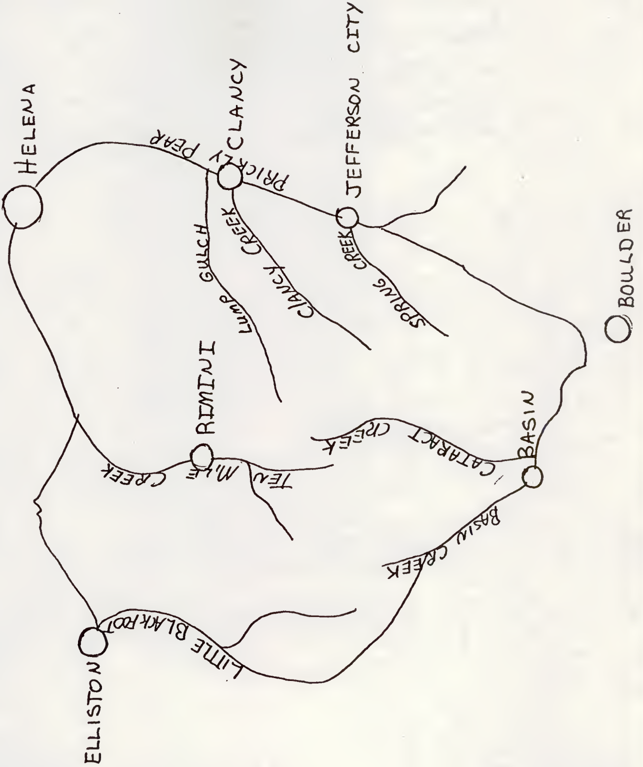


FIGURE 1. INDEX MAP SHOWING LOCATION AND STRUCTURAL SETTING OF THE BOULDER BATHOLITH

(Batholiths shown by stipple. B, Butte; H, Helena; GF, Great Falls; M, Missoula)

FIGURE 2

NORTHERN BOULDER BATHOLITH STUDY AREA



Demand and increasing prices for metals have spurred a renewed interest and development of mining activity in the Northern Boulder Batholith. Reopening of old mines, processing of old mill tailings, and development of new mining properties are rapidly increasing. An evaluation of the impact of previous mining activities and an assessment of future mining impacts as related to water quality are needed.

# MINING PROBLEMS

Mining operations expose vast quantities of previously undisturbed material. This exposed material is subject to the natural weathering processes of oxidation and erosion which produce acid, dissolve metals, and transport sediment. These materials severely impact streams, lakes, and/or groundwater.

## Acid Mine Drainage

Base metal sulfide compounds exposed to air and water are oxidized, forming acid mine drainage. The most common of these compounds is iron sulfide, usually termed "pyrite" ($FeS_2$).

Acid is formed as a result of a series of interrelated reactions which are given below:

$$\underset{\text{(pyrite)}}{FeS_{2(S)}} + 7/2O_2 + H_2O \rightarrow \underset{\text{(Ferrous ion)}}{Fe^{+2}} + 2SO_4 + 2H^+ \tag{1}$$

$$\underset{\text{(Ferrous ion)}}{Fe^{+2}} + \tfrac{1}{4}O_2 + H^+ \longrightarrow \underset{\text{(Ferric ion)}}{Fe^{+3}} + \tfrac{1}{2}H_2O \tag{2}$$

$$\underset{\text{(Ferric ion)}}{Fe^{+3}} + 3H_2O \longrightarrow \underset{\text{(Ferric Hydroxide)}}{Fe(OH)_3} + 3H^+ \tag{3a}$$

$$\underset{\text{(Ferric ion)}}{2Fe^{+3}} + XH_2O \longrightarrow \underset{\text{(Hydrous ferric oxide)}}{Fe_2O_3 \cdot XH_2O} + 6H^+ \tag{3b}$$

$$FeS_2(S) + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3(S) + 2H_2SO_4 \tag{4}$$

When pyrite is exposed to oxygen and water, sulfide is oxidized to sulfate, releasing acid, sulfate, and ferrous ion (Reaction 1). Ferrous ion is then oxidized to ferric ion (Reaction 2). At normal pH range (6-8), ferric ion hydrolyzes to hydrous ferric oxide, a gelatinous floc commonly called yellow boy (Reaction 3b). Frequently, this precipitate is shown as ferric hydroxide (Reaction 3a). This floc coats the bottom of a stream polluted by acid mine drainage. By summing reactions 1 through 3b, shown by reaction 4, the oxidation of one mole of pyrite produces four equivalents of acidity.

Acid reaching waters may be harmful not only in producing adverse acid conditions, but also by increasing the toxicity of various constituents in the waters. Often, the natural buffering capabilities (equilibrium) of a stream are upset by acid mine drainage to such a degree that aquatic life is depressed or destroyed.

### Heavy Metals

Either independently or synergistically, heavy metals dissolved in water can have adverse effects on aquatic organisms. Historically, miners in search of gold left behind other ores such as pyrite, copper, lead and zinc. These overlooked materials cause pollution problems in receiving waters.

The mechanism by which metals are transported to the stream is quite simple. Pyrite is oxidized to acid; this acid dissolves ores laden with heavy metals which are carried to the stream by runoff and/or mine seeps.

### Sedimentation

Transportation of sediment to waters is a naturally occurring condition which has been accelerated by mining. The principal contributors are erosion of mine dumps, tailings piles, settling ponds, and access roads. Weather conditions, size of mine waste particles, and slope of land are factors in determining the amount of sediment reaching a stream.

Sediments, which blanket the bottom of a stream, lamage or destroy invertebrate populations, block spawning beds, and may remove dissolved oxygen. These sediments may contain concentrations of heavy metals or other deleterious constituents.

# ABATEMENT

Abatement of acid mine drainage (AMD) can be attained by using physical or chemical methods. Physical methods (revegetation, mine sealing, stream diversion, removal of ore) and chemical methods (neutralization, flash distillation, ion exchance) can be used either independently or with one another.

## PHYSICAL METHODS:

### Revegetation

Most mine dumps and tailings are not capable of supporting plant life because of poor soil conditions. Water from rain or snow leaches through these mine wastes oxidizing compounds on its way. Covering mine wastes with good soil and revegetating it with deep rooted plants capable of absorbing water helps correct the leaching problem. Revegetation can also dry up mine seeps by lowering groundwater levels in the area. Revegetation costs about $1,000 per acre (Bhatt, Doyle, and Rapp, February, 1974). Revegetation is only partially effective as it does not prevent all water from leaching through the mine wastes.

### Mine Sealing

Mine seeps loaded with acid and metals usually come from adits, drifts, slopes, shafts, subsidence holes, fractures and other openings into underground mines. A way to control mine seeps and prevent oxidation of compounds is by using a mine seal.

Mine sealing is defined as the closure of mine entries with clay, earth, rock, timber, concrete blocks, brick, steel, concrete, fly ash, or other suitable material.

Mine seals are classified into three categories:

1) Dry Seal - A dry seal prevents air and water from entering a mine. This type of seal is used at openings with no or a very small discharge.

2) Air Seal - An air seal is designed to prevent air from entering a mine, but permits water to flow from the mine.

3) Hydraulic Seal - A hydraulic seal is used to prevent the flow of water from a mine.

The cost of individual mine seals ranges from $8,300 to $58,000 (Bhatt, Doyle, and Rapp, February, 1974). Many mine seals are not adequate to exclude air from underground workings and they may not last indefinitely. If discharges are blocked, the acid water may find a new discharge opening.

### Stream Diversion

In many instances, mine waste is placed very near a stream. When this is the case, pollution hazards are the greatest. One way of alleviating this problem is to divert the stream away from these sources. The use of impervious material such as plastic pipe for the diversion will prevent the stream from contacting mine wastes.

Studies have shown the cost per linear foot of stream diversion ranges from $12 to $27 (Bhatt, Doyle, and Rapp, February, 1974).

Stream diversions control, but do not correct acid mine drainage.

The mine waste is still exposed to the natural weathering processes of erosion and oxidation.

### Removal of Mine Waste

If mine dumps or tailings piles are near a stream or in a natural drainage, it is beneficial to remove the waste from this area. This process involves the physical hauling of the waste to an area where it will not be subject to as much erosion and oxidation. Here again, the problem is not corrected, but only moved to an area where it causes less impact.

## CHEMICAL METHODS:

### Neutralization

Neutralization is a process involving mixing of alkali with acid mine waters to neutralize acid and precipitate contaminating metals. The precipitated metals can then be separated by sedimentation and/or filtration. This process involves construction of a plant to carry out the neutralization procedure and operation and maintenance of the plant on a year round basis.

The cost of treating mine drainage by neutralization will vary with the quantity of drainage requiring treatment, the initial quality and desired final quality, and availability of land for the treatment plant. Available cost data indicates construction of a neutralization plant costs more than $100,000 with an annual operating cost of more than $20,000.

### Flash Distillation

Flash distillation removes water by vaporization leaving behind all contaminants. As shown in EPA's "Analysis of Pollution Control Costs", the construction of a plant large enough to handle 5 million gallons per day would require an investment of 14.2 million dollars and an operation and maintenance cost of $3.40 per 1,000 gallons of acid mine discharge.

### Ion Exchange

Reaction of metal salts with specific anionic and cationic resins is called ion exchange. The acid mine discharge is passed through an ionic exchanger which removes harmful constituents. Construction of a .5 million gallon per day plant costs $2,485,000 with an operating cost of .2 cents per 1,000 gallons of treated waste (Bhatt, Doyle, and Rapp, February, 1974).

There are several other chemical methods for treatment of acid mine drainage. Most are similar to those discussed above in that they require construction of a permanent plant and need year round maintenance and operation. It must be pointed out that chemical treatment results in a by-product which may also be a pollutant to receiving waters.

# TASKS

On Friday, May 13, 1977, an aerial survey of the Northern Boulder Batholith was conducted. Existing mines, adits, and tailings were located and plotted on 15 minute United States Department of the Interior Geological Survey maps. These locations were then visited to determine impact to water quality in the area.

Water samples were collected from streams and mine seeps and analyzed by the Chemistry Laboratory, Department of Health and Environmental Sciences. Parameters measured were: pH, specific conductance, sulfate, and total recoverable metals (arsenic, cadmium, copper, iron, lead, manganese, mercury, silver, and zinc).

Sulfate and pH indicate the acidic tendencies of the water while specific conductance reflects the general character of the water. Concentration of heavy metals is shown by total recoverable metals. All samples were collected, preserved, and analyzed in accordance with U.S. Environmental Protection Agency recommended methods.

Flow of seeps and streams was determined at the time of sample collection. Periphyton samples were collected from streams and analyzed by Loren Bahls, Water Quality Specialist, Water Quality Bureau. Periphyton analysis will indicate if there is a stress to the stream's biological community.

By reviewing these and existing data, determination of impacts to streams is possible.

# RESULTS

Results of the Northern Boulder Batholith study are given by drainage (Boulder River, Prickly Pear Creek, Ten Mile Creek, and the Little Blackfoot River). Figures 3 through 6 are schematic diagrams of the four drainages showing station locations where stream samples have been collected. Date sampled, water flow rate, and analytical results are listed by drainage and station location in Appendix A.

The influence of toxic metals on aquatic life has been studied extensively. Due to differences in stream chemistry, the toxicity of metals is different for different streams. Table 2 shows concentrations having an adverse effect on aquatic organisms and recommended limits for drinking water as stated by National Interim Primary Drinking Water Standards.

TABLE 1. RECOMMENDED LIMITS FOR CERTAIN TOXIC ELEMENTS*

| Element | Effect on Aquatic Life (concentration in milligrams per Liter) | Recommended Limits for Drinking Water (concentration in milligrams per Liter) |
|---|---|---|
| Arsenic (As) | 1.1 | .05 |
| Cadmium (Cd) | .0005 | .01 |
| Copper (Cu) | .025 | 1.0 |
| Iron (Fe) | .2 | .3 |
| Lead (pb) | .1 | .05 |
| Manganese (Mn) | 1.0 | .05 |
| Mercury (Hg) | .008 | .002 |
| Silver (Ag) | .003 | .05 |
| Zinc (Zn) | .01 | 5.0 |

* See Appendix B

Field observations that follow were made by the author, in April, 1977 to September, 1977. They will be grouped by drainage and treated in a downstream order within each drainage. Along with field observations are periphyton summarized results. The periphyton report is given in its entirety in Appendix C.

"It is important to iterate that the periphyton samples reflect conditions that were in effect only on or shortly before the date of collection and in no way can be construed to reflect conditions that prevail seasonally or from year to year at a given site (Loren Bahls)."

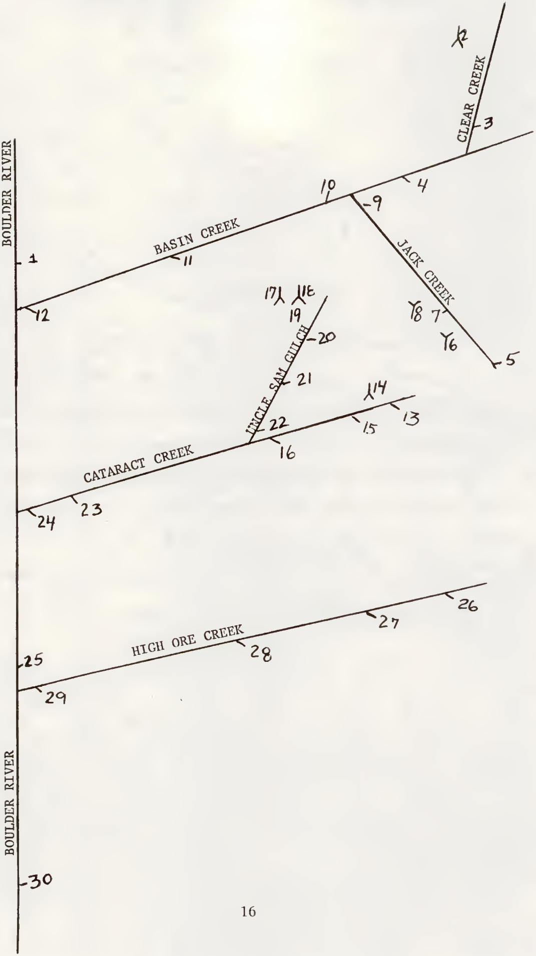
## BOULDER RIVER DRAINAGE

The Boulder River Drainage (Figure 3) is located in the Basin (Cataract), Comet (Amazon), and Boulder mining districts. Lodes were discovered in this area prior to 1870 and active mining has persisted since that time (Water Resources Survey, June 1956).

The Boulder River Drainage has many mine sites, both abandoned and active. Mine sites were most numerous near Upper Basin Creek, Cataract Creek, and High Ore Creek.

The ground survey revealed about two miles of Basin Creek to be affected by placer mining.

FIGURE 3. THE BOULDER RIVER DRAINAGE



## FIELD OBSERVATIONS

### BASIN CREEK AT WINTERS CAMP (4)

Basin Creek at Winters Camp had an abundance of aquatic insects and aquatic flora. There appeared to be no stress to the stream from mining.

#### Periphyton

The sample from this site contained more non-diatom genera (9) than any other. Diatom diversity $(\bar{d})$ and equitability (e) were also sufficiently high to preclude any possibility of serious stress on the periphyton community.

### CRYSTAL MINE (18)

This fairly large active mine has a severe impact to waters in the area. The seep from the adit was at one time contained by construction of a holding pond. This pond has since washed out, allowing the mine seep to reach Uncle Sam Gulch. Every surface the mine water contacts is iron stained. All plant life in contact with the mine water appears to have died.

Water comes into contact with the mine dump which is placed in a natural drainage. This water appears to be carrying an appreciable amount of metals and acid.

### UNCLE SAM GULCH BELOW CRYSTAL MINE (21)

Uncle Sam Gulch at this site appears to be completely sterile. No aquatic insects were seen and the stream bottom was coated with an orange floc. All flora in contact with Uncle Sam Gulch seems to be dead.

## HIGH ORE CREEK BELOW COMET MINE (27)

High Ore Creek below the Comet Mine is choked with sediment. No aquatic insects were found in the stream.

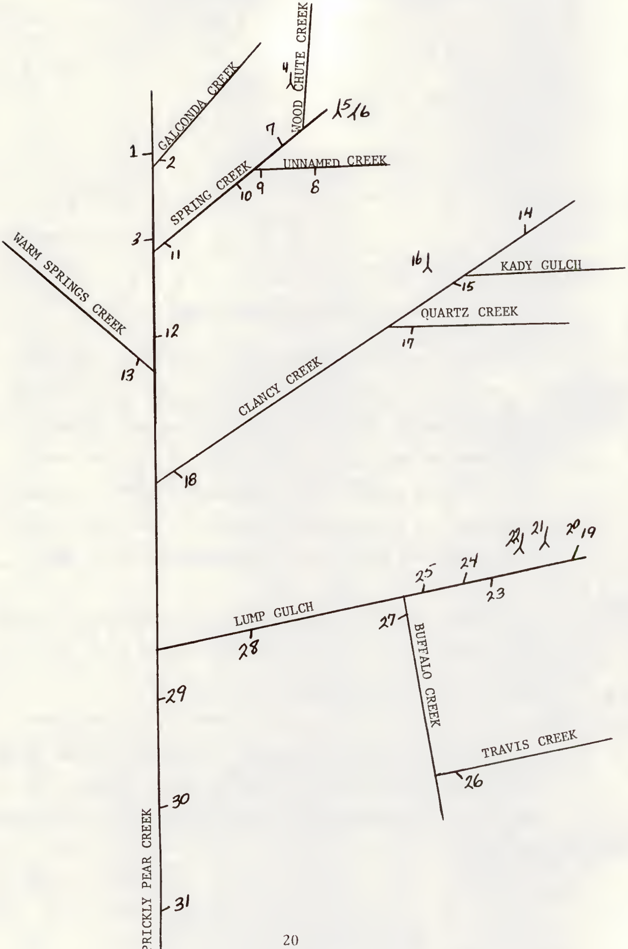
## PRICKLY PEAR CREEK DRAINAGE

Gold was discovered near Montana City in 1862. After this discovery, Prickly Pear Creek was the scene of much placer mining which continued until 1948. Upper Prickly Pear and its tributaries (Figure 4) are mostly found in the Wicks-Corbin-Gregory mining district. This mining district contained many mines, both small and large. The Alta, Gregory, and Washington Mines were more productive than other mines in the drainage (Water Resources Survey, June, 1956).

An aerial survey revealed this whole area to be dotted with mine sites. Numerous mine sites were observed near Alta Mountain, Upper Spring Creek, and Upper Clancy Creek.

A total of 13.17 in the 41.01 miles of Prickly Pear Creek (from East Helena to Jefferson City) is altered by dredging (Bishop and Peck, September 26, 1962). The ground survey revealed about 4½ miles of lower Clancy Creek is also altered by past placer mining activities.

FIGURE 4. THE PRICKLY PEAR CREEK DRAINAGE



## FIELD OBSERVATIONS

### PRICKLY PEAR ABOVE GALCONDA (1)

Prickly Pear above Galconda Creek is a cool flowing, high quality mountain stream. There was an abundance of aquatic insects. The stream appeared undisturbed by man.

#### Periphyton

Diatoms were abundant at this site and except for one trichome of *Anabaena*, they were the only algae present in the sample. In spite of the fact that the numbers of diatom taxa identified and counted were higher than average, $\bar{d}$ and e were marginal.

### GALCONDA CREEK JUST BELOW MINE DUMP (2)

An old mine dump is very near Galconda Creek in its lower reaches. Although there was no seep entering Galconda Creek, there was evidence of stress to the stream. The creek bottom was covered with sediment and no aquatic insects were observed.

#### Periphyton

The sample from this site contained only a few filaments representing two genera of non-diatom algae and scattered diatom cells in 12 different taxa. The diatoms were too sparse for a proportional count, hence it is presumed that the periphyton community at this site had been under severe stress.

### MINE SEEP ON WOOD CHUTE CREEK (4)

This abandoned mine has a very large discharge in comparison to other mine discharges in the area. The seep comes from an old adit and flows directly into Wood Chute Creek. Wood Chute Creek was not flowing and the water from the mine adit flowed underground within one quarter mile of the adit. There was a brilliant orange floc on surfaces in contact with the mine seep.

## SEEP FROM WASHINGTON MINE (5)

Washington Mine has a series of tailings ponds which have been washed out in the past. The seep from this mine flows through these ponds and carries an appreciable amount of sediment. This water flows into a small drainage and eventually reaches Spring Creek.

## SEEP AT BASE OF ALTA MOUNTAIN (6)

This seep appears to come from the mines on top of Alta Mountain. It had a flow of one gallon per minute and entered an unnamed tributary of Spring Creek.

## SPRING CREEK AT BRIDGE SOUTH OF CORBIN (7)

Spring Creek at this site had a moderate amount of aquatic insects and bottom flora.

### Periphyton

Algal material was generally abundant in this sample, but the senescent condition of the principal alga, Vaucheria, may indicate that the flora was at some stage of decline at the time of collection. However, $\bar{d}$ and e values were high, indicating that any stress, if present, had a negligible effect on the diatom association.

## WATER JUST BELOW TAILINGS ABOVE CORBIN (8)

This water flows beside a series of tailings ponds just above

Corbin. There was a lot of sediment in the stream. No aquatic insects were found.

## UNNAMED CREEK FLOWING THROUGH CORBIN (9)

This small stream flows through tailings piled in Corbin. It picks up a large amount of sediment and has a typical acid mine look. The stream flows directly into Spring Creek. No aquatic life was observed here.

## SPRING CREEK JUST BELOW CORBIN (10)

Spring Creek at this point appeared to be severely stressed by the unnamed creek flowing through Corbin. The stream bottom was choked with sediment and rocks were stained orange. No aquatic insects were observed.

### Periphyton

Diatoms were very sparse in the sample from this station and the $\bar{d}$ and e values were both below the threshold levels indicating significant impact. The diatom flora was dominated by the "pioneering" *Achnanthes* spp.

## SPRING CREEK AT JEFFERSON CITY

Spring Creek appeared to be severely stressed at this site. Sediment coated the stream bottom, rocks were iron stained, and no aquatic insects were seen.

### Periphyton

Diatoms were more common here than below Corbin, but the association had the fewest taxa counted (3) and the lowest diversity

(0.061) of any sample. Again, Achnanthes spp. dominated the diatom flora. Only one genus of non-diatom algae (Entophysalis) was present. The periphyton community apparently was under extreme stress.

## WARM SPRINGS CREEK AT MOUTH (13)

Some sediment was observed on the creek bottom, but an abundance of aquatic insects was found.

### Periphyton

Diatoms were the only algae apparent in this sample and they were very sparse. However, a fairly large number of taxa were represented and $\bar{d}$ and e values were both high, possibly indicating no significant stress.

## CLANCY CREEK ABOVE KADY GULCH (14)

There appeared to be no stress to Clancy Creek at this station.

### Periphyton

The sample from this point contained abundant algal material including two genera of blue-green algae. The dominant diatom species, Synedra ulna, Navicula lanceolata, and Cymbella minuta, indicate water with higher than average dissolved solids. Diversity and equitability were both relatively high and the community was probably not under stress.

## CLANCY CREEK BELOW KADY GULCH (15)

Other than a small amount of sediment in the stream bottom, there seemed to be no stress to the stream.

### Periphyton

Both the diatom and non-diatom floras were more diverse below Kady Gulch than above, but equitability was somewhat lower. The high PRA[1] values of Navicula lamii and Nitzschia spp. at this station indicate considerable nutrient (probably nitrogen) enrichment. However, there does not seem to be any significant effect on periphyton community structure.

## WATER FLOWING THROUGH GREGORY MINE (16)

Gregory Mine has several piles of mine waste near it. A small stream of water flows around the base of these piles. The further the water flows, more sediment is picked up and more orange floc appears. The water flows into Clancy Creek.

## QUARTZ CREEK (17)

Quartz Creek had some sediment in the creek bottom. Aquatic insects were abundant.

### Periphyton

The Quartz Creek sample contained a meager amount of algal material. Diatoms were sparse and $\bar{d}$ and e values were marginal, indicating a moderate amount of stress on the periphyton community.

## CLANCY CREEK AT BRIDGE WEST OF CLANCY (18)

Moderate amounts of aquatic insects were found at this station. A small amount of sediment coated the stream bottom.

---

[1] Percent Relative Abundance (PRA)

### Periphyton

This sample was dominated by Hydrurus foetidus, a common algae of cold headwater streams in the spring of the year. Diatoms were common, reasonably diverse and equitably distributed among the taxa. The rather high PRA for Nitzschia spp. indicates moderate nitrogen enrichment. Otherwise, no appreciable impact could be detected.

## NELLIE GRANT MINE WATER (21)

The Nellie Grant Mine is being explored by Sparrow Resources for further development. The water from the adit is contained in a small pond. Rocks were coated with "yellow boy".

## LUMP GULCH JUST ABOVE BUFFALO CREEK (25)

Lump Gulch at this site had an abundance of aquatic insects and the stream bottom had a healthy growth of flora.

### Periphyton

The upper Lump Gulch collection contained three genera of non-diatom algae. Diatoms were abundant and the PRA of Nitzschia spp. was higher in this sample (44.7%) than in any other, indicating significant nitrogen enrichment. Other than this, the diatom association appeared to be reasonably healthy.

## TRAVIS CREEK (26)

Travis Creek was coated with sediment at the time of sampling. There was no evidence of an acid mine discharge impacting the stream at the time of sampling.

Periphyton

Diatoms were the only algae found in the sample from this stream, but they were abundant. Travis Creek had the highest numbers of diatom taxa counted and identified of any stream sampled. Diversity and equitability values were also among the highest, indicating no appreciable stress on the periphyton community.

### BUFFALO CREEK (27)

Buffalo Creek is a cold, clear creek appearing to have no stress at the time of sampling.

Periphyton

Diatoms were sparse and ranked second behind the green alga Tetraspora in the sample from this stream. The dominant diatom taxon was Rhoicosphenia curvata, a species thriving in water of high alkalinity and nutrient content. Diatom diversity and equitability were borderline.

### LUMP GULCH BELOW TAILINGS (28)

Just upstream from this sampling site, mine tailings had been dumped next to the stream. Although aquatic insects were in abundance, some sediment was seen in the stream. If the tailings have an impact on the stream, it seemed to be minimal at the time of sampling.

Periphyton

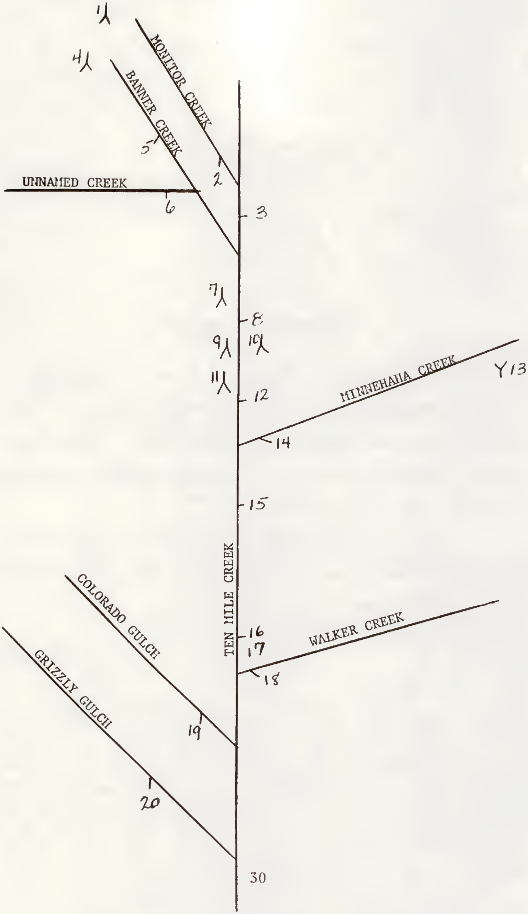
This Lump Gulch sample contained diatoms in abundance as well as two genera of non-diatom algae. The diatom flora was fairly diverse and the cells were equitably distributed among the taxa. No significant impact was apparent.

## TEN MILE CREEK DRAINAGE

The Ten Mile Creek Drainage is located in the Rimini or Vaughn mining district. The district was discovered in 1870. Most production occured from 1885 until 1900. Mining in the area has been sporadic from 1900 to the present (Water Resources Survey, June 1957).

The aerial survey showed many mining sites in and above Rimini including Upper Ten Mile, Monitor Creek, Banner Creek, Red Mountain, and Old Baldy Mountain.

FIGURE 5. THE TEN MILE CREEK DRAINAGE



# FIELD OBSERVATIONS

## PORPHRY DIKE MINE (1)

This abandoned mine is located near Monitor Creek. A small seep flows from the adit over the mine dump and goes underground.

## MONITOR CREEK (2)

Monitor Creek has a significant amount of sediment in its channel. Aquatic insects were present in small numbers.

### Periphyton

This sample had a rather sparse flora both in terms of amount and kinds of algae. *Achnanthes* spp. accounted for about half of the diatom population. The $\bar{d}$ and e values indicate borderline conditions.

## UPPER TEN MILE CREEK (3)

Upper Ten Mile Creek at this site has cool flowing water with an abundance of aquatic insects. It appears to have little or no man-caused stress.

### Periphyton

This sample had luxuriant and apparently healthy growths of both diatom and non-diatom algae. Although the number of diatom taxa was on the low side, the $\bar{d}$ and e values indicate favorable conditions. The dominant diatom taxon was *Diatoma hiemale* var. *mesodon*, which indicates cool flowing water with fairly low conductivity.

## PEERLESS MINE (4)

The Peerless Mine is a large abandoned mining operation. The caved in adit has a seep coming from it with a small amount of iron precipitate. The seep eventually reaches Banner Creek.

### BANNER CREEK (5)

Banner Creek had a good population of aquatic insects. Rocks were stained rust-brown.

#### Periphyton

The Banner Creek sample had an ample and diverse flora with no indication of even the slightest stress on the periphyton community.

### UNNAMED CREEK NEAR RED MOUNTAIN (6)

This small tributary to Banner Creek had an abundance of aquatic insects. It appeared to be unaffected by man.

#### Periphyton

This tributary to Banner Creek had a moderately rich flora indicating no significant stress on the periphyton community.

### SEEP FROM MINE ABOVE RIMINI (7)

This abandoned mine is located very near Ten Mile Creek and has a mine dump sloping down to the creek. The mine seep comes from an old adit and coats surfaces with a brilliant orange, iron precipitate. The seep flows over the mine dump directly into Ten Mile Creek. The City of Helena's drinking water diversion is approximately one-quarter mile downstream from this site.

## TEN MILE CREEK ABOVE RIMINI (8)

Very few aquatic insects were found at this site. Rocks in the stream bed were stained rust-brown.

### Periphyton

This sample had only one species of non-diatom algae and a sparse diatom population dominated by *Achnanthes* spp. Diatom species diversity and equitability had the third lowest values among the 31 samples that were counted, and both values were under the threshold level indicating severe stress.

## GENERAL MINE (9)

This mine is being explored by Sparrow Resources and is located on the southern edge of Rimini. There is no seep from this mine although a water sample was collected from standing water in the mine shaft.

## LEE MOUNTAIN MINE (10)

This mine is directly west of the General Mine and is also being explored by Sparrow Resources. The small seep coming from the adit is held in a pond. There is an orange floc in the bottom of the pond.

## VALLEY FORGE MINE (11)

This mine is located in the heart of Rimini near Ten Mile Creek. The mine has a seep which flows down the mine dump into Ten Mile Creek. An appreciable amount of orange floc can be seen here.

## TEN MILE CREEK BELOW RIMINI (12)

The rocks on the creek bottom were stained rust-brown. Just a few aquatic insects were found here.

### Periphyton

As with Ten Mile Creek above Rimini, this sample had only one species of non-diatom algae and a depauperate diatom flora dominated by *Achnanthes* spp. There were six fewer taxa here than above Rimini and this was reflected in a correspondingly lower diversity index, which was the second lowest recorded for the entire study, unsurpassed only by the Spring Creek sample at Jefferson City. Conspicuous in this sample was a rusty-brown colored floc. The periphyton community here appeared to be under even greater stress than the community above Rimini.

## JUSTICE MINE SEEP (13)

Justice Mine is a small abandoned mine with a caved in adit. The adit has a seep coming from it which flows across the mine dump and goes underground. There is an iron precipitate on all surfaces touched by mine water.

## MINNEHAHA CREEK NEAR MOUTH (14)

This sample point was just above another of the City of Helena's water diversions. Aquatic insects were present, but not in abundance.

### Periphyton

Diatoms were the only algae in this sample and they were very sparse. The dominant taxon, Navicula minima, is an indicator of waters with higher alkalinity and nutrient values. Diversity and equitability values were borderline.

### TEN MILE CREEK AT USGS GAGING STATION (15)

This station appeared to have high quality water. Aquatic insects and fish were seen here.

#### Periphyton

This sample had 4 genera of non-diatom algae in addition to an abundance of diatoms. The number of diatom taxa and the $\bar{d}$ and e values were all higher than corresponding values for the two Ten Mile Creek samples from above and below Rimini. The dominant diatom was Synedra minuscula, which "prefers cool water". The algal flora here reflected a moderate amount of stress on the periphyton community.

### TEN MILE CREEK ABOVE WALKER CREEK (16)

Ten Mile Creek at this site appeared to be unaffected by man. Aquatic insects were abundant at this site.

### NATURAL SEEP JUST ABOVE WALKER CREEK (17)

This seep came from the stream bank and flowed directly into Ten Mile Creek. There was an orange precipitate where the seep flowed. Its effect upon Ten Mile Creek appeared to be minimal.

### WALKER CREEK NEAR MOUTH (18)

This cool flowing stream appeared unstressed at the time of sampling.

## COLORADO GULCH (19)

This small stream flows through a densely populated area. There was quite a bit of stream bottom growth indicating man-caused nutrient load may be having an effect on Colorado Gulch.

### Periphyton

Although diatoms were the only significant algae at this station, they were present in abundance and at comfortably high levels of diversity and equitability. The dominant taxon was *Navicula lanceolata*, which is an alkaliphilous, eutrophic species that "seems to prefer water of high mineral content".

## GRIZZLY GULCH (20)

This site was just below a glory hole mine. Sediment coated the stream bottom.

### Periphyton

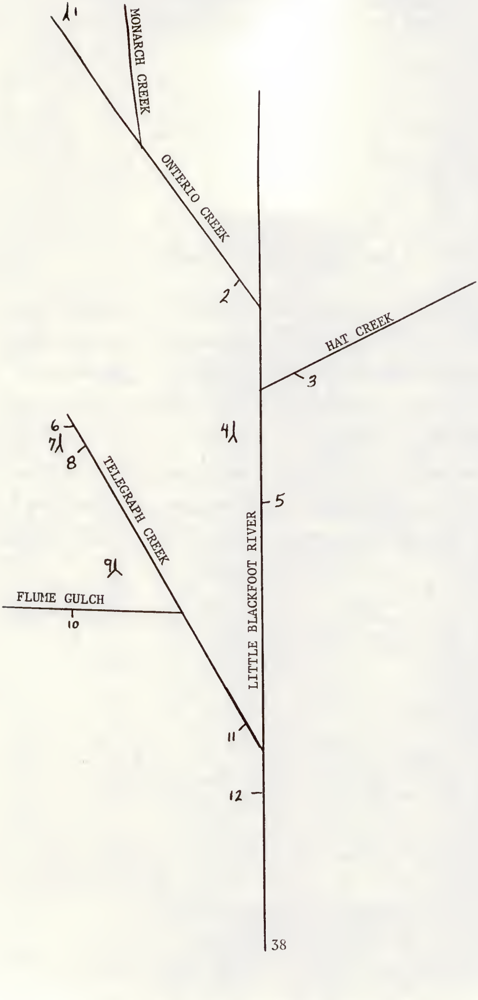
Diatoms were the only algae in this sample and they were sparse, dominated by *Achnanthes* spp. A borderline e value may indicate moderate stress on the periphyton community.

## LITTLE BLACKFOOT RIVER DRAINAGE

The Little Blackfoot above Elliston is in the heart of the Elliston (Onterio, Negro Hill) mining district. Gold was first discovered in this district before 1870. Many gold and silver mines were active between 1890 and 1909. Metal mining has been sporadic since that time.

The aerial survey revealed many mine sites throughout the Little Blackfoot Drainage. Most sites were concentrated around Negro Mountain, Monarch Creek, Onterio Creek, and Upper Telegraph Creek.

FIGURE 6. THE LITTLE BLACKFOOT RIVER DRAINAGE



# FIELD OBSERVATIONS

## ONTERIO MINE SEEP (1)

Water from the Onterio Mine flows from an old adit and has been diverted around the mine dump. The bottom of the seep channel is coated with an iron precipitate. This water goes underground before it reaches any stream.

## ONTERIO CREEK NEAR MOUTH (2)

Onterio Creek is a cold, high quality mountain stream. The stream bottom has good biological growth with large numbers of aquatic insects.

### *Periphyton*

There was a considerable amount of algal material in the sample taken at this site. Although diatoms were more abundant than the other groups, only 10 diatom taxa were identified altogether and two of those taxa - *Hannaea arcus* and *Diatoma hiemale* var. *mesodon* - contributed 97.5 percent of the individual cells counted. Both these taxa indicate cool flowing waters, and although $\bar{d}$ and e values were both borderline, the low diatom diversity at this site is probably due to stenothermal and oligothermal conditions rather than to some man-caused stress.

## HAT CREEK (3)

Hat Creek is a tributary to the Little Blackfoot and appears to have high quality water. An abundance of aquatic insects was noticed.

Periphyton

An abundance of Nostoc and a rich and equitably distributed diatom flora in the sample from this site all indicate the lack of any significant impact on the periphyton community.

SEEP FROM MINE ON NEGRO MOUNTAIN (4)

The bottom of this mine seep channel is coated with an iron precipitate. This water flows out of an adit and eventually reaches the Little Blackfoot. There has not been any mining activity at this site for quite some time.

LITTLE BLACKFOOT BELOW CHARTER OAK MINES (5)

The Little Blackfoot at this station appears to be unaffected by natural or man-made causes. Charter Oak Mine is just above this site on Negro Mountain. There is activity at this mine, but there appears to be no discharge to the Little Blackfoot.

Periphyton

An abundance of Ulothrix and a rich and equitably distributed diatom flora in the sample from this site all indicate no appreciable stress on the periphyton community from either natural or cultural sources.

TELEGRAPH CREEK JUST ABOVE LILY-ORPHAN MINE (6)

This sample point is very near the headwaters of Telegraph Creek. The bottom of the stream has an appreciable amount of sediment in it.

Periphyton

This sample included a rusty-brown floc similar to that in Ten

Mile Creek below Rimini. Although diatoms were sparse and the only algae present, they comprised a rich equitably distributed flora. Whatever impacts there may be at this site, they apparently have not affected the diatom flora. On the other hand, the diatom community sampled here was possibly not produced on the site, but recently transported from unaffected reaches upstream.

### LILY-ORPHAN BOY MINE SEEP (7)

This abandoned mine has a seep flowing directly into Telegraph Creek. There is a large amount of rust-brown floc coating surfaces that the mine water flows over. The mine tailings were dumped directly into Telegraph Creek. Telegraph Creek has eroded a channel through these tailings.

### TELEGRAPH CREEK JUST BELOW LILY-ORPHAN BOY MINE (8)

Telegraph Creek is choked with sediment at this point. There was hardly any stream bottom growth and no aquatic insects were found. The stream bottom was coated with an orange-brown floc.

#### Periphyton

The brown floc was again conspicuous in the sample from this stream. Other than the very few, mostly dead diatom cells, the algal flora consisted of only one short filament of *Hormidium*, quite possibly drifted in from upstream. Diatoms were scarcer than in Telegraph Creek above Lily-Orphan and too sparse to perform a proportional count. The total number of taxa *identified* was half the number *counted* in the sample from above the mine. Thus, the stress on the periphyton community at this point was apparently severe.

## WATER FROM ADIT AT HUB CAMP (9)

Hub Camp is an old mining camp with two adits. There was water flowing from one of these adits. The seep channel had no floc.

## FLUME GULCH (10)

Flume Gulch has some sediment; otherwise, it appears to be undisturbed by man-made causes.

## TELEGRAPH CREEK JUST BELOW HAHN CREEK (11)

There appears to be no stress on Telegraph Creek at this point. There was an abundance of aquatic insects here and general water quality looked good.

### Periphyton

The sample from this location contained a richer than average non-diatom flora dominated by *Tolypothrix* and *Ulothrix*, and a reasonably diverse and equitably distributed diatom flora. Algal growth, as indicated by the sample, was healthy and luxuriant. Apparently, the stress that was evident at the next upstream station (Telegraph below Lily-Orphan) was not felt at this point.

## LITTLE BLACKFOOT AT BRIDGE - SECTION 19 (12)

The Little Blackfoot is noted for high quality water which is characterized by this sample point. There appears to be no stress from mining at this point. An abundance of algal growth and aquatic insects are present.

### Periphyton

An abundance of *Zygnema* and *Ulothrix* and a rich and equitably distributed diatom flora in the sample collected at this site indicate no discernible stress on the periphyton community. (Diatom diversity was higher here than at any of the other stations sampled.)

# CONCLUSION

Almost all streams in the Northern Boulder Batholith are affected from past and present mining activities. Fifty-six of sixty-six stream sample locations had metal concentrations exceeding those known to cause an impact on aquatic organisms. Some streams are severely stressed by acid mine drainage.

Concentration of pollutants seem to be the greatest during periods of high flow. This is due to water from runoff carrying oxidation by-products, dissolved metals, and sediment to receiving waters. Samples collected represent stream quality at that particular time and do not reflect the water quality year round.

## BOULDER RIVER DRAINAGE

The Boulder River Drainage is well documented as having degraded water quality due to mine waste.

"Toxic metals discharged from mine seeps upstream of Boulder, Montana are present in the Boulder River in concentrations reported to cause avoidance reactions to migrating fish, thus, blocking existing or potential spawning runs from downstream. Fish food production, fish growth, and spawning success are inhibited severly in some tributaries in portions of the Boulder River. Water quality impairment is due principally to input of sediment and toxic metals from the High Ore and Cataract Creek drainages (Braico and Botz, December, 1974)."

The Boulder River above Basin is relatively free from mining related pollution. Basin Creek carries an appreciable amount of iron and zinc, probably due to seeps from the Josephine Mine near

Clear Creek and the Morning and Bullion Mines near Jack Creek.

The Crystal Mine severely impacts Uncle Sam Gulch and lower Cataract Creek. "Aquatic insects were not present in Uncle Sam Gulch below the Crystal Mine and were not found in Cataract Creek 3 miles below the confluence with Uncle Sam Gulch (Elser and Marcoux, April, 1972)." The Eva May Mine also contributes a metal load to Cataract Creek.

High Ore Creek is sterile below the Comet Mine. The stream flows through old mine tailings picking up sediment and heavy metals.

In comparing parameter concentrations and recommended limits, all sites except for Boulder River above Basin, Basin Creek at Winters Camp, Jack Creek above and below Vindicater Mine, and Basin Creek above the reservoir, had metal concentrations exceeding those known to cause an impact on aquatic organisms.

## PRICKLY PEAR CREEK DRAINAGE

Prickly Pear Creek and Clancy Creek were sites of intense placer mining activity for many years which severely damaged stream beds with sediment and disturbance of the natural alluvium. The abandonment of placer mines years ago has allowed these two streams to naturally recover to some extent.

Spring Creek is severely impaired by mine waste and contributes a tremendous load of sediment and heavy metals to Prickly Pear Creek. Spring Creek is stressed by mine seeps from Alta Mountain, Wood Chute Creek, and the Washington Mine. A small stream flowing through tailings piles dumped in Corbin severely impacts Spring

Creek below that town. As indicated by analytical results, Spring Creek carries the greatest load of pollutants during spring runoffs.

Gregory Mine and many smaller mines deliver an appreciable amount of pollutants to upper Clancy Creek. Observations made (presence of sediment in the stream bed) indicate Clancy Creek contributes a pollutant load to Prickly Pear at certain times of the year.

Even though the Froehner and Nellie Grant Mine seeps flow into the headwaters of Lump Gulch Creek and have an impact on these headwaters, the stream appears to be unstressed in its lower reaches.

## TEN MILE CREEK DRAINAGE

Upper Ten Mile Creek and its tributaries were relatively free from pollutants at the time of sampling. Two mines (Porphry Dike and Peerless) have seeps which have a slight influence on the upper reaches of Ten Mile Creek. These problems would be especially prevalent during spring runoff.

The most drastic pollution problems in the Ten Mile Drainage were observed in and very near to the town of Rimini. A seep from the mine above Rimini flows into Ten Mile Creek about one-quarter of a mile above the City of Helena's water diversion. This mine and the three mines (Grant, Lee Mountain, and Valley Forge) in Rimini, degrade Ten Mile Creek for a number of miles downstream.

The Justice Mine seep near upper Minnehaha Creek is very concentrated in metals and acid. Even though the seep went underground before reaching the creek, the effects were noticed (e.g., zinc concentration of .34 mg/L at the mouth of Minnehaha Creek). During periods of high runoff, one can expect concentrations of metals and acid in Minnehaha Creek to increase. Minnehaha Creek is also a source for Helena's drinking water.

With the exception of Grizzly Gulch, lower Ten Mile Creek and its tributaries appeared unstressed by mine related pollutants. Grizzly Gulch is impaired by sediment and it carries a measurable amount of iron.

## LITTLE BLACKFOOT RIVER DRAINAGE

With the exception of the headwaters of Telegraph Creek, the Little Blackfoot River and its tributaries are relatively free from pollution. Lily-Orphan Mine has degraded two to five miles of Telegraph Creek.

Most mine seeps in the drainage are in an area where they do not flow into any stream. This appears to be the reason why stress on waters in the Little Blackfoot Drainage are minimal.

# DISCUSSION AND RECOMMENDATIONS

High quality mountain streams capable of supporting an abundance of aquatic life are severely degraded by pollutants from carelessly planned mining operations. Stress from acid mine drainage and improperly placed mine waste is evident in the Northern Boulder Batholith waters. This degradation has been prevalent for years and without corrective action, the stress to streams will remain for many years to come.

Abatement of acid mine drainage is very costly, and desired results are not always achieved. The best method of controlling this pollution is to harness the pollutants before they reach the streams.

Hard rock mining will increase in the future and without proper planning, good quality mountain streams will be drastically degraded. Large mining companies along with small miners are actively mining and exploring for previously undiscovered mineral deposits. Some mining operations are using existing adits, tailings, and mine dumps to recover metals either left behind, or undiscovered by past mining operations. Most abandoned mine shafts have since filled with groundwater degraded by dissolved metals and acid. In order for miners to use the mine shaft, the water must be removed. If this poor quality water is allowed to reach a stream, the results to the stream would be devastating.

The New Hard Rock Law, Title 50, Chapter 12, of the R.C.M. (Revised Codes of Montana), 1947 states:

> *An act requiring the licensing of persons engaged in mining exploration and related activities requiring permits for the conduct of development, mining and related activities: Providing for the reclamation of explored, developed, and mined land: Providing for the administration and enforcement of said act by the Board of State Lands and investments; and Providing for an appeal procedure; and Providing an effective date.*

Most hard rock mine operations within the State are classified as small miners. "Small miner" means any person, firm, or corporation engaged in the business of mining who does not remove from the earth during any calendar year, material in excess of 36,500 tons in the aggregate [Section 50-1203(15)].

Section 19 of the New Hard Rock Law states:

> EXEMPTION OF SMALL MINERS -- WRITTEN AGREEMENT -- NON-COMPLIANCE A MISDEMEANOR. *No provisions of this act shall apply to any small miner when the small miner annually agrees in writing:*
>
> (1) *That he shall not pollute or contaminate any stream;*

Section 21 of the Law states:

> INFORMATION OBTAINED FROM APPLICATIONS CONFIDENTIAL -- ADMISSIBLE IN HEARINGS OR PROCEEDINGS. *Any and all information obtained by the board or by the director or his staff by virtue of applications for exploration licenses, and all information obtained from small miners, is confidential between the board and the applicant, except as to the name of the applicant and the county of proposed operation.*

The confidentiality between small miners and the Board of State Lands makes it impossible for the Water Quality Bureau of the Department of Health and Environmental Sciences to advise miners on control of wastes, unless miners themselves request this advice. In many instances, miners are not aware of pollution problems resulting from their operations. These problems may not be evident for years, by which time, a high quality mountain stream may be severely degraded. Proper placement of mine dumps and tailings, proper construction of roads and mill sites, and containment or treatment of acid mine waters would reduce pollution from hard rock mines.

In order to alleviate present and future pollution problems from hard rock mines, the following recommendations are made:

1) The following mine drainages are causing severe pollution to receiving waters in the Northern Boulder Batholith. The most feasible method of eliminating these pollution sources should be determined. If the cost and effectiveness of these methods are reasonable, the abatement should be carried out.

- Crystal Mine on Uncle Sam Gulch
- Comet Mine on High Ore Creek
- Mine seeps entering Spring Creek (Washington Mine, mine on Wood Chute Creek)
- Tailings near Spring Creek in Corbin
- Mine seeps entering Clancy Creek
- Mine seeps entering Ten Mile Creek in and near Rimini
- Justice Mine seep near Minnehaha Creek
- Lily-Orphan Mine dump and seep on upper Telegraph Creek

2) To determine severity of pollution from acid mine drainage on a year round basis, monitoring programs are recommended for the following drainages:

- Boulder River Drainage
    1) Uncle Sam Gulch at mouth
    2) Cataract Creek at mouth
    3) High Ore creek at mouth

- Prickly Pear Creek Drainage
    1) Spring Creek at mouth
    2) Clancy Creek at mouth

- Ten Mile Creek Drainage
    1) Ten Mile Creek just above City of Helena's drinking water diversion

    2) Ten Mile Creek below Rimini
    3) Minnehaha Creek at mouth

- Little Blackfoot Drainage
    1) Telegraph Creek at mouth

These stations should be sampled four times a year (winter, during spring runoff, summer low flow, and fall). Flows should be determined at the time of sampling; samples should be analyzed for periphyton, pH, conductivity, TSS, sulfate, and total recoverable metals (arsenic, cadmium, copper, manganese, lead, and zinc).

3) Revise section 21 of the New Hard Rock Law to include the Department of Health and Environmental Sciences.

4) Advise miners prior to development as to proper construction and placement of roads and mills, proper placement of mine wastes (mine dump and tailings), and treatment of acid mine wastes.

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# APPENDICES

# APPENDIX A. PARAMETER LEVELS OF WATERS IN THE NORTHERN BOULDER BATHOLITH

PARAMETER LEVELS IN THE BOULDER RIVER DRAINAGE

| Station Number | Station Location & Date | Flow (cfs) | pH | Conductivity (umohs) | Concentration (Mg/L) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 1, | Boulder River above Basin<br>07/08/75 | --- | 7.5 | 59 | --- | <.01 | --- | <.001 | .01 | .69 | --- | --- | <.05 | .02 |
| | 01/10/76 | --- | 7.75 | 150 | --- | <.01 | --- | <.001 | <.01 | .27 | --- | --- | <.05 | .01 |
| | 02/08/76 | --- | 7.6 | 160 | --- | --- | --- | <.001 | <.01 | .28 | --- | --- | <.05 | <.01 |
| | 03/10/76 | --- | 7.4 | 159 | --- | --- | --- | <.001 | <.01 | .54 | --- | --- | <.05 | .02 |
| | 04/09/76 | --- | 7.35 | 99 | --- | --- | --- | <.001 | .01 | 1.4 | --- | --- | <.05 | .05 |
| 2 | Josephine Mine Seep<br>07/12/72 | --- | 3.5 | 350 | --- | --- | --- | --- | .09 | 1.6 | --- | --- | <.01 | .51 |
| 3 | Clear Creek<br>07/12/72 | --- | 6.8 | 30 | --- | --- | --- | --- | .01 | .31 | --- | --- | <.01 | <.01 |
| 4 | Basin Creek at Winters Camp<br>07/20/77 | 20 | 7.4 | 71 | 9.2 | <.05 | .018 | <.005 | <.01 | .11 | --- | <.01 | <.05 | .01 |
| 5 | Jack Creek above Vindicator Mine<br>09/26/77 | 1.5 | 6.6 | 89 | 16 | <.01 | .003 | <.01 | <.01 | .06 | --- | .01 | <.05 | <.01 |
| 6 | Morning Mine Seep<br>07/13/72 | --- | 8.2 | 500 | --- | --- | --- | --- | .05 | .21 | --- | --- | <.05 | .01 |
| 7 | Jack Creek below Vindicator Mine<br>09/26/77 | 2.0 | 6.5 | 91 | 14 | <.01 | .004 | <.01 | <.01 | .05 | --- | .02 | <.05 | <.01 |
| 8 | Bullion Mine Seep<br>07/13/77 | --- | 2.5 | 3450 | --- | --- | --- | --- | .03 | .69 | --- | --- | <.05 | .07 |

Continued.

| Station Number | Station Location & Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Concentration (Mg/L) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 9 | Jack Creek at Mouth 07/12/72 | --- | 7.5 | 74 | --- | --- | --- | --- | .08 | .69 | --- | --- | <.05 | .10 |
| 10 | Basin Creek above South Fork of Basin Creek - 11/17/72 | 2.4 | 7.4 | 69 | 14 | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 11 | Basin Creek above Reservoir 09/26/75 | 15 | 6.3 | 84 | 19 | --- | .007 | <.01 | <.01 | .14 | --- | --- | <.05 | .10 |
| 12 | Basin Creek at Mouth 04/27/75 | --- | 7.3 | 98 | --- | <.01 | --- | <.001 | <.01 | .15 | --- | --- | <.02 | .20 |
| | 05/11/75 | --- | 7.3 | 99 | --- | <.01 | --- | .001 | .03 | .50 | --- | --- | <.02 | .31 |
| | 06/10/75 | --- | 7.0 | 34 | --- | <.01 | --- | <.001 | .02 | 1.2 | --- | --- | <.05 | .11 |
| 13 | Cataract Creek above Eva May Mine 06/13/72 | 15 | 7.5 | 59 | --- | --- | --- | --- | .03 | .52 | --- | --- | .02 | .03 |
| 14 | Eva May Mine Seep 06/13/72 | 5 GPM | 6.8 | 670 | --- | --- | --- | --- | .09 | 2.4 | --- | --- | .008 | .25 |
| 15 | Cataract Creek below Eva May Mine 09/15/72 | .30 | 7.4 | --- | 10 | --- | .08 | --- | .02 | .33 | --- | | .01 | .01 |
| 16 | Cataract Creek just above Uncle Sam Gulch - 06/13/72 | --- | 7.3 | 63 | --- | --- | --- | --- | .08 | .72 | --- | --- | .003 | .28 |

Continued

| Station Number | Station Location & Date | Flow (cfs) | pH | Conductivity (umohs) | Concentration (Mg/L)<br>Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Cataract Creek at Mouth | | | | | | | | | | | | | |
| | 05/11/75 | --- | 7.6 | 129 | --- | <.01 | --- | .007 | .23 | 1.1 | --- | --- | .02 | .66 |
| | 06/10/75 | --- | 7.2 | 49 | --- | <.01 | --- | .001 | .09 | .85 | --- | --- | <.05 | .25 |
| 25 | Boulder River just above High Ore Creek | | | | | | | | | | | | | |
| | 02/08/76 | --- | 7.5 | 155 | --- | --- | --- | <.001 | .02 | .22 | --- | --- | <.05 | .15 |
| | 03/10/76 | --- | 7.4 | 133 | --- | --- | --- | <.001 | .06 | 2.0 | --- | --- | <.05 | .35 |
| | 04/09/76 | --- | 7.5 | 102 | --- | --- | --- | --- | .02 | 1.1 | --- | --- | <.05 | .09 |
| 26 | High Ore Creek above Comet Mine | | | | | | | | | | | | | |
| | 06/12/72 | --- | 7.5 | 74 | --- | --- | --- | --- | .03 | .93 | --- | --- | <.05 | .03 |
| 27 | High Ore Creek below Comet Mine | | | | | | | | | | | | | |
| | 06/12/72 | --- | 8.1 | 170 | --- | --- | --- | --- | .06 | .88 | --- | --- | .03 | .02 |
| | 07/15/77 | 2.0 | 7.4 | 690 | 162 | <.05 | 1.8 | .018 | .12 | 11 | <.0002 | 9.5 | 1.2 | 9.0 |
| 28 | High Ore Creek 2 miles from mouth | | | | | | | | | | | | | |
| | 06/12/72 | --- | 8.1 | 370 | --- | --- | --- | --- | .04 | 2.1 | --- | --- | .02 | .34 |
| 29 | High Ore Creek at Mouth | | | | | | | | | | | | | |
| | 04/27/75 | --- | 7.6 | 327 | --- | <.01 | --- | .015 | .03 | 2.3 | --- | --- | .13 | 3.9 |
| | 05/11/75 | --- | 7.6 | 248 | --- | <.01 | --- | .024 | .15 | 7.5 | --- | --- | .64 | 5.7 |
| | 06/10/75 | --- | 7.5 | 157 | --- | .01 | --- | .016 | .21 | 19 | --- | --- | <.05 | 4.2 |

Continued.

| Station Number | Station Location & Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Concentration (Mg/L) Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | Seep near active part of Crystal Mine<br>07/07/77 | 15 GPM | 7.2 | 160 | 4.6 | <.05 | .027 | <.005 | .03 | .35 | <.0002 | .23 | <.05 | .08 |
| 18 | Crystal Mine Seep<br>07/07/77 | 56 GPM | 2.9 | 1383 | 260 | <.05 | 6.1 | --- | --- | 100 | <.0002 | 16 | .38 | 87 |
| 19 | Water Leaking from Holding Pond<br>07/07/77 | 10 GPM | 2.9 | 1395 | 638 | <.05 | 3.8 | .93 | 22 | 72 | <.0002 | 16 | .35 | 88 |
| 20 | Water below Mine Dump - 07/07/77 | .3 | 4.3 | 234 | 78 | <.05 | .05 | .08 | 1.5 | 1.7 | <.0002 | 2.7 | .08 | 9.6 |
| 21 | Uncle Sam Gulch below Crystal Mine<br>06/12/72<br>09/15/72<br>10/06/75<br>07/07/77 | ---<br>.26<br>2.4<br>1.0 | 6.8<br>7.4<br>6.8<br>3.7 | 45<br>---<br>161<br>417 | ---<br>10<br>55<br>132 | ---<br>---<br><.01<br><.05 | ---<br><.01<br>.003<br>.23 | ---<br>---<br>---<br>.18 | .52<br>.15<br>.52<br>3.1 | 2.9<br>1.0<br>.05<br>3.0 | ---<br>---<br>---<br><.0002 | ---<br>---<br>.91<br>3.4 | .03<br>.02<br><.05<br>.08 | .04<br>.11<br>5.1<br>17 |
| 22 | Uncle Sam Gulch at Mouth - 09/15/72 | .24 | 7.0 | 600 | 56 | --- | <.01 | --- | .03 | .67 | --- | --- | .02 | .26 |
| 23 | Cataract Creek 1 mile from Mouth<br>09/15/72<br>11/13/74<br>06/12/75 | 3.4<br>---<br>220 | 7.7<br>7.9<br>7.1 | 160<br>148<br>52 | 21<br>---<br>13 | ---<br>---<br><.01 | <.01<br>.004<br>.006 | ---<br>---<br><.01 | .04<br>.07<br>.05 | .19<br>.15<br>.22 | ---<br>---<br><.0002 | ---<br>---<br>.03 | .02<br><.01<br><.05 | .10<br>.96<br>.19 |

Continued.

| Station Number | Station Location & Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Concentration (Mg/L) | | | | | | | | | |
| 30 | Boulder River at Boulder | | | | | | | | | | | | | |
| | 07/28/75 | --- | 7.7 | 57 | --- | <.01 | --- | <.001 | .06 | .70 | --- | --- | <.05 | .11 |
| | 01/10/76 | --- | 7.7 | 157 | --- | <.01 | --- | <.001 | .02 | .21 | --- | --- | <.05 | .24 |
| | 02/08/76 | --- | 7.5 | 172 | --- | --- | --- | <.001 | .02 | .28 | --- | --- | <.05 | .28 |
| | 03/10/76 | --- | 7.5 | 153 | --- | --- | --- | <.001 | .03 | 1.5 | --- | --- | .05 | .30 |
| | 04/09/76 | --- | 7.5 | 103 | --- | --- | --- | .001 | .04 | .75 | --- | --- | <.05 | .16 |

PARAMETER LEVELS IN THE PRICKLY PEAR DRAINAGE

|  |  |  |  |  | Concentrations (mg/1) |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 1 | Prickly Pear just above Galconda<br>05/18/77 | 12.59 | 7.6 | 73 | 9.4 | <.01 | .002 | <.005 | <.01 | .12 | --- | <.01 | .05 | <.01 |
| 2 | Galconda Creek just below mine dump<br>05/18/77 | 1.24 | 7.6 | 90 | 4.7 | <.01 | .002 | <.005 | <.01 | .14 | <.0002 | .01 | .05 | .01 |
| 3 | Prickly Pear above Spring Creek<br>05/12/75 | 100 | --- | 200 | --- | --- | <.001 | <.001 | .07 | 1.8 | --- | .25 | <.02 | .05 |
| 4 | Mine seep on Wood Chute Creek<br>06/07/77 | .30 | 7.0 | 1145 | 675 | <.01 | 5.1 | .12 | .23 | 17 | --- | 13 | 1.6 | 24 |
| 5 | Seep from Washington Mine<br>06/07/77 | 50 GPM | 7.2 | 654 | 200 | <.01 | .18 | .005 | <.01 | 5.9 | --- | 2.9 | <.05 | 3.1 |
| 6 | Mine seep at base of Alta Mountain<br>06/07/77 | 1 GPM | 6.0 | 818 | 445 | <.01 | .004 | <.005 | <.01 | 37 | --- | 18 | <.05 | .72 |
| 7 | Spring Creek at bridge South of Corbin<br>06/07/77 | 3.27 | 7.8 | 388 | 137 | <.01 | .019 | <.005 | .01 | .16 | --- | .03 | <.05 | .04 |
| 8 | Water just below tailings above Corbin<br>06/07/77 | --- | 7.5 | 712 | 215 | <.01 | .001 | .018 | .46 | .89 | <.0002 | .59 | <.05 | 1.4 |

Continued

| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Concentrations (mg/1) | | | | | | | | | |
| 9 | Unnamed Creek flowing through Corbin<br>06/09/77 | .37 | 2.9 | 2356 | 1210 | <.01 | .025 | .30 | 3.0 | 50 | .0005 | 155 | <.05 | 115 |
| 10 | Spring Creek just below Corbin<br>05/12/75<br>06/09/77 | ---<br>2.51 | ---<br>7.0 | 1050<br>476 | ---<br>153 | ---<br><.01 | .35<br>.01 | .238<br>.013 | 14<br>.14 | 71<br>2.7 | ---<br><.0002 | 53<br>7.8 | 2.2<br><.05 | 60<br>5.5 |
| 11 | Spring Creek at Jefferson City<br>05/12/75<br>06/09/77 | 20<br>2.88 | ---<br>7.1 | 9500<br>484 | ---<br>158 | ---<br><.01 | <.001<br>.017 | .376<br>.013 | 8.0<br>.13 | 76<br>2.4 | ---<br>.0002 | 160<br>8.0 | 25<br><.05 | 112<br>5.4 |
| 12 | Spring Creek 2 miles below Jefferson City<br>05/12/77 | --- | --- | 600 | --- | --- | 1.14 | .238 | 4.6 | 53 | --- | 81 | 20 | 55 |
| 13 | Warm Springs Creek at Mouth<br>05/18/77 | 9.88 | 7.8 | 202 | 21 | <.01 | .023 | <.005 | <.01 | .64 | <.0002 | .06 | <.05 | .04 |
| 14 | Clancy Creek above Kady Gulch<br>06/07/77 | 1.04 | 7.6 | 268 | 95 | <.01 | .003 | <.005 | <.01 | .50 | --- | .48 | <.05 | .10 |
| 15 | Clancy Creek below Kady Gulch<br>06/07/77 | 2.04 | 7.7 | 234 | 70 | <.01 | .005 | <.005 | <.01 | .31 | --- | .28 | <.05 | .02 |
| 16 | Water Flowing thru Gregory Mine<br>06/07/77 | 2 GPM | 6.7 | 403 | 188 | <.01 | .34 | .018 | .32 | 18 | --- | .99 | .10 | 1.9 |

Continued

| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Concentrations (mg/l) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 17 | Quartz Creek near Mouth 06/06/77 | 4.32 | 8.0 | 170 | 18 | <.01 | .002 | <.005 | <.01 | .21 | <.0002 | .03 | <.05 | <.01 |
| 18 | Clancy Creek at bridge west of Clancy 06/06/77 | 1.53 | 8.0 | 261 | 49 | <.01 | .011 | <.005 | <.01 | .22 | <.0002 | .03 | <.05 | .02 |
| 19 | Lump Gulch above Frohner Mine 06/28/73 | --- | 7.1 | 56 | --- | --- | <.01 | --- | .09 | 1.2 | --- | --- | <.01 | <.01 |
| | 05/20/76 | --- | --- | --- | --- | --- | --- | --- | <.01 | .74 | --- | --- | <.01 | <.01 |
| | 09/21/76 | --- | --- | --- | --- | --- | --- | --- | <.01 | .10 | --- | --- | .13 | <.01 |
| 20 | Spring near Nellie Grant Mine 07/05/77 | --- | 6.1 | 179 | 48 | <.05 | .30 | .030 | .20 | 1.1 | .0003 | .72 | .10 | 3.9 |
| 21 | Water in Nellie Grant Mine 07/05/77 | --- | 6.3 | 167 | 36 | <.05 | .001 | .046 | .08 | 6.9 | <.0002 | .56 | <.05 | 15 |
| 22 | Frohner Mine Seep 06/28/73 | --- | 3.0 | 840 | --- | --- | 1.1 | --- | .07 | 40 | --- | --- | .10 | 1.8 |
| 23 | Lump Gulch below Frohner 06/28/73 | --- | 6.9 | 89 | --- | --- | <.01 | --- | .04 | .85 | --- | --- | .05 | .96 |
| | 05/20/76 | --- | --- | --- | --- | --- | --- | --- | <.01 | .47 | --- | --- | <.05 | .18 |
| | 09/21/76 | --- | --- | --- | --- | --- | --- | --- | .02 | 2.1 | --- | --- | .13 | 1.6 |

Continued

| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Concentrations (mg/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 24 | Headgate on Lump Gulch Creek 05/20/77 | --- | --- | --- | --- | --- | --- | --- | <.01 | .20 | --- | --- | <.05 | .10 |
| 25 | Lump Gulch just above Buffalo Creek 05/14/77 | 1.82 | 7.9 | 169 | 19 | <.01 | .002 | <.005 | <.01 | .09 | <.0002 | <.01 | <.05 | <.01 |
| 26 | Travis Creek near Mouth 05/14/77 | .43 | 7.5 | 288 | 93 | <.01 | <.001 | <.005 | <.01 | .90 | <.0002 | .15 | <.05 | <.01 |
| 27 | Buffalo Creek near Mouth 05/14/77 | 1.87 | 7.7 | 277 | 86 | <.01 | .001 | <.005 | <.01 | .39 | <.0002 | .03 | <.05 | .01 |
| 28 | Lump Gulch just below mine tailings 05/19/77 | 7.70 | 7.8 | 223 | 52 | <.01 | .001 | <.005 | <.01 | .44 | <.0002 | .03 | <.05 | <.01 |
| 29 | Prickly Pear 5 miles below Clancy<br>06/21/73<br>05/17/74 | 38<br>47 | 8.2<br>8.0 | 183<br>189 | 28<br>40 | ---<br>--- | <.01<br>.005 | <.01<br><.001 | .01<br><.01 | .29<br>.32 | ---<br>--- | ---<br>.90 | .02<br>--- | .10<br>.12 |
| 30 | Prickly Pear above ASARCO - 06/28/76 | --- | --- | --- | --- | --- | --- | --- | .01 | .47 | --- | --- | <.05 | .27 |
| 31 | Prickly Pear at East Helena<br>06/28/76<br>11/17/76 | ---<br>--- | ---<br>8.0 | 174<br>301 | ---<br>--- | ---<br>--- | .007<br>.004 | .001<br><.001 | .02<br>.01 | .95<br>.36 | ---<br>--- | .26<br>.10 | <.05<br>--- | .20<br>.13 |

PARAMETER LEVELS IN THE TEN MILE DRAINAGE

| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Concentrations (mg/l) |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 1 | Seep from Porphry Dike Mine 07/13/77 | 5 GPM | 3.5 | 203 | 43 | <.05 | <.001 | <.005 | .03 | 1.3 | .0003 | .10 | <.05 | .19 |
| 2 | Monitor Creek 07/13/77 | .87 | 6.7 | 44 | 10 | <.05 | <.001 | <.005 | <.01 | .06 | <.0002 | <.01 | <.05 | <.01 |
| 3 | Upper Ten Mile Creek 07/13/77 | 3.38 | 7.0 | 39 | 6.6 | <.05 | <.001 | <.005 | <.01 | .13 | <.0002 | <.01 | <.05 | <.01 |
| 4 | Seep from Peerless Mine 07/13/77 | 6 GPM | 6.3 | 353 | 115 | <.05 | .003 | .008 | .22 | 5.2 | <.0002 | 6.2 | .10 | 1.4 |
| 5 | Banner Creek 07/13/77 | 1.90 | 7.0 | 66 | 9.6 | <.05 | <.001 | <.005 | <.01 | .64 | <.0002 | .20 | <.05 | .04 |
| 6 | Unnamed Creek near Red Mountain 07/13/77 | 1.66 | 7.4 | 48 | 7.6 | <.05 | <.001 | <.005 | <.01 | <.05 | <.0002 | <.01 | <.05 | <.01 |
| 7 | Seep from mine above Rimini - 07/13/77 | 15 GPM | 6.9 | 551 | 155 | <.05 | --- | .070 | .03 | 2.5 | --- | 5.4 | <.05 | 13 |
| 8 | Ten Mile Creek above Rimini - 04/06/77 | 1.88 | 7.4 | 97 | 23 | --- | .019 | <.005 | <.01 | .23 | --- | .08 | --- | .60 |
| 9 | General Mine 07/05/77 | no flow | 3.0 | 179 | 656 | --- | --- | --- | --- | 100 | --- | 1.7 | --- | 39 |
| 10 | Lee Mountain Mine 07/05/77 | no flow | 2.5 | 2122 | 1028 | <.05 | .25 | .32 | .36 | 190 | <.0002 | 16 | .45 | 58 |

Continued.

| Station Number | Station Location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Concentrations (mg/1) | | | | | | | | | |
| 11 | Valley Forge Mine Seep 04/06/77 | 7 GPM | 4.4 | 2201 | 600 | --- | 4.0 | .49 | .61 | 153 | --- | 1.6 | --- | 47 |
| 12 | Ten Mile Creek below Rimini - 04/06/77 | 1.06 | 6.3 | 330 | 126 | --- | .08 | .02 | .07 | 2.8 | --- | .79 | --- | 3.9 |
| 13 | Seep from Justice Mine 07/12/77 | 5 GPM | 2.8 | 2080 | 1140 | <.05 | .027 | .72 | 2.0 | 60 | <.0002 | 17 | .52 | 150 |
| 14 | Minnehaha Creek near Mouth - 07/12/77 | .74 | 7.0 | 106 | 20 | <.05 | <.001 | <.005 | .01 | <.05 | <.0002 | <.01 | <.05 | .34 |
| 15 | Ten Mile Creek at Gaging Station 04/06/77 | .76 | 7.2 | 219 | 53 | --- | .034 | <.005 | <.01 | .15 | --- | .05 | --- | .50 |
| 16 | Ten Mile Creek just above Walker Creek 04/06/77 | 17.82 | 7.4 | 69 | --- | <.05 | .017 | <.005 | <.01 | .18 | --- | .03 | <.05 | .22 |
| 17 | Natural Seep just above Walker Creek 05/20/77 | 5 GPM | 7.0 | 159 | 18 | <.01 | .043 | <.005 | <.01 | 8.0 | --- | .51 | <.05 | <.01 |
| 18 | Walker Creek near Mouth - 05/06/77 | 1.31 | 7.6 | 147 | --- | <.05 | .007 | <.005 | <.01 | .50 | --- | .04 | <.05 | <.01 |
| 19 | Colorado Gulch 05/20/77 | --- | 7.7 | 183 | 17 | <.05 | .003 | <.005 | <.01 | .78 | <.0002 | .05 | <.05 | <.0 |
| 20 | Grizzly Gulch below Glory Hole 05/14/77 | .42 | 7.9 | 320 | 25 | <.01 | .011 | <.005 | <.01 | 1.4 | <.0002 | .12 | <.05 | <.0 |

## PARAMETER LEVELS IN THE LITTLE BLACKFOOT RIVER DRAINAGE

| Station Number | Station location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Concentrations (mg/1) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 1 | Onterio Mine Seep 06/01/77 | 10 GPM | 3.1 | 595 | 52 | <.01 | 4.5 | .015 | .08 | 27 | <.0002 | 1.2 | .23 | 3.3 |
| 2 | Onterio Creek near Mouth - 05/20/77 | 31.51 | 7.6 | 43 | 7.4 | <.01 | .008 | <.005 | <.01 | .09 | --- | <.01 | <.05 | .01 |
| 3 | Hat Creek near mouth 05/20/77 | 2.55 | 8.2 | 199 | 9.5 | <.01 | .002 | <.005 | <.01 | .04 | --- | <.01 | <.05 | <.01 |
| 4 | Seep from Mine on Negro Mountain 05/20/77 | 15 GPM | 6.8 | 198 | 47 | <.01 | .21 | <.005 | <.01 | 13 | <.0002 | 1.7 | <.05 | .26 |
| 5 | Little Blackfoot below Charter Oak Mines 05/20/77 | 49.15 | 7.4 | 85 | 9.0 | <.01 | .009 | <.005 | <.01 | .06 | --- | <.01 | <.05 | <.01 |
| 6 | Telegraph Creek above Lily-Orphan Mine 06/01/77 | .40 | 6.6 | 34 | 11.0 | <.01 | .003 | <.005 | <.01 | .76 | --- | .05 | <.05 | <.01 |
| 7 | Lily-Orphan Mine Seep 06/01/77 | 4 GPM | 3.0 | 999 | 365 | <.01 | 12 | .24 | .36 | 48 | <.0002 | 9.8 | .08 | 26 |
| 8 | Telegraph Creek just below Lily-Orphan Mine 06/01/77 | .47 | 6.2 | 60 | 16.0 | <.01 | .029 | .005 | .01 | .41 | <.0002 | .30 | <.05 | .53 |

Continued

| Station Number | Station location and Date | Flow (cfs) | pH | Conductivity (umohs) | Sulfate | Concentrations (mg/1) |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Ag | As | Cd | Cu | Fe | Hg | Mn | Pb | Zn |
| 9 | Water from Adit at HUB Camp<br>06/01/77 | 1 GPM | 7.8 | 500 | 142 | < .01 | .050 | < .005 | .04 | 3.2 | < .0002 | .10 | <.05 | .11 |
| 10 | Flume Gulch<br>06/01/77 | --- | 7.6 | 63 | 9.9 | < .01 | .011 | <.005 | <.01 | 1.2 | --- | .06 | <.05 | <.01 |
| 11 | Telegraph Creek just below Hahn Creek<br>06/01/77 | 8.73 | 7.7 | 68 | 7.7 | <.01 | .004 | < .005 | < .01 | .14 | <.0002 | .01 | <.05 | .02 |
| 12 | Little Blackfoot bridge, Section 19<br>05/20/77 | 45.6 | 7.5 | 93 | 9.7 | <.01 | .007 | < .005 | < .01 | .08 | --- | <.01 | <.05 | <.01 |

# APPENDIX B. Summary of Water Quality Criteria

# APPENDIX C. Stream Phycoperiphyton of the Northern Boulder Batholith as an Indicator of Water Quality

PROVISIONAL

# STREAM PHYCOPERIPHYTON OF THE NORTHERN BOULDER BATHOLITH AS AN INDICATOR OF WATER QUALITY

SEPTEMBER 1977

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# SUMMARY

Composite samples of attached algae (phycoperiphyton) were collected from natural substrates at 33 locations in the northern Boulder Batholith during spring and early summer 1977. The samples were from 21 different streams that contribute headwater flows to three major drainages: Missouri-Smith, Upper Clark Fork, and Upper Missouri River tributaries. Samples were analyzed for overall algal abundance, relative abundance of non-diatom genera, relative abundance of diatom taxa, and diatom community structural parameters.

The periphyton community was apparently under severe stress at two locations by virtue of an almost complete dearth of algal material in the samples and insufficient diatoms with which to perform a proportional count. These locations were Golconda Creek below tailings and Telegraph Creek below Lily-Orphan Boy Mine. The periphyton communities at four additional locations also appeared to be under severe stress as evidenced by abnormally low diatom diversity and equitability values. These locations were Tenmile Creek above and below Rimini and Spring Creek below Corbin and at Jefferson City. Borderline values for periphyton community parameters indicated the algal floras were under moderate stress at eight other locations.

Algae in the division Chrysophyta (golden-brown algae) dominated the stream phycoperiphyton of the northern Boulder Batholith primarily as a result of the preponderance of diatoms in the collections. The remainder of the algal flora was shared almost coequally by the Chlorophyta (green algae) and the Cyanophyta (blue-green algae). Altogether, non-diatom algae were identified in 23 genera and 4 divisions; diatoms were identified in 36 genera, 180 species and 209 varieties.

Algal abundance and variety for the northern Boulder Batholith appear to be low by Montana standards, probably because of natural growth limitations inherent in the low temperature, low nutrient waters draining this high elevation, granitic area. Diatom indicator taxa show little organic nitrogen enrichment and adequate dissolved oxygen levels on the average.

## METHODS

Composite periphyton samples were collected from natural substrates per instructions in the attached procedural memo dated June 20, 1977 (APPENDIX A). Sampling sites (Table 1) were selected at the discretion of the principal investigator, Richard Pedersen, who collected all of the samples described herein.

Samples were preserved with Lugol's (IKI) solution and returned to Helena for analyses. A subsample (a few drops) of each raw sample was scanned microscopically under low power, to determine the following: 1) whether the algae in the sample, particularly the diatoms, were living or dead when the sample was collected; 2) what kinds (genera) of non-diatom algae were present; and 3) what was the abundance of the different genera of non-diatom algae relative to one another and to the diatoms as a group.

Another, larger subsample was subsequently acidified and oxidized with a few milliliters of concentrated technical grade sulfuric acid and a few crystals of potassium dichromate, respectively. After return to room temperature and effective dissipation of the organic fraction of the subsample, the suspension of diatom frustules was brought to neutrality by repeated dilutions and decantations with distilled water. A permanent strewn mount of diatom frustules was then prepared according to the method outlined by the EPA (1973) using Cargille's "CARMOUNT-165 MEDIUM".

Each strewn mount was scanned under oil (1000 X) and a list of diatom taxa for that sample was compiled. (Diatom taxa were identified to species and to variety where possible using available references,) Then a diatom proportional count was performed for each strewn mount following the procedure outlined by EPA (1973), except that in excess of 300 (not 250) cells were tallied. Proportional count results were then used to compute percent relative abundance (PRA) for all taxa, and diatom community diversity ($\bar{d}$) and equitability (e) as recommended by EPA (1973):

$$\bar{d} = \frac{C}{N} (N \log_{10} N - \Sigma n_i \log_{10} n_i)$$

where C = 3.321928, N = total number of individuals, and $n_i$ = total number of individuals in the $i$th species; and

$$e = \frac{s'}{s}$$

where s = number of taxa in the sample and s' = number of taxa expected in the community if it conforms to MacArthur's broken stick model.

## RESULTS

### General

Periphyton samples were collected at 33 locations on 21 different streams draining the northern portion of the Boulder Batholith (Table 1). The streams sampled contribute headwater flows to three major drainages: Missouri-Smith, Upper Clark Fork, and Upper Missouri River Tributaries. All samples appeared to contain at least some algae that were living at the time of collection although in certain samples the algal flora was very sparse and very simple.

## Non-Diatom Flora

Twenty-eight of the samples contained non-diatom algae and one sample contained an aquatic moss in addition to diatoms (Table 2). Non-diatom algae were identified in 23 genera and 4 major groups (divisions). Most of the non-diatom algae were fairly equally distributed among the Chlorophyta (green algae) and Cyanophyta (blue-green algae) with lesser amounts of Chrysophyta (golden-brown algae) and Rhodophyta (red algae)(Table 3).

## Diatom Flora

All 33 of the samples contained diatoms, 4 of them diatoms exclusively (Table 2). Overall, diatoms dominated the phycoperiphyton of the streams sampled; other non-diatom taxa in the same division, primarily Tribonema, further contributed to floral domination by the Chrysophyta (Table 3).

Diatoms were too sparse in 2 of the 33 samples (0280A and 0313A) to permit proportional counts. Between 304 and 359 cells were tallied in each of the remaining 31 samples for a total of 10,112 diatom cells counted. Represented among these cells were 36 genera, 180 species and 209 identified varieties (Table 4). Many species and varieties could not be identified using available references.

Twenty-three diatom taxa contributed at least 10 percent relative abundance (10 PRA) in one or more samples. The PRA for each of these so-called "major taxa" in each of the 31 samples counted is listed in Table 5. Achnanthes minutissima Kütz. was by far the most common diatom taxon encountered.

Selected diatom community parameters for each sample are listed in Table 6. An explanation and interpretation of these parameters will be included in the following section.

## INTERPRETATION

Three characteristics of the periphyton samples are used to evaluate possible water quality problems and subsequent stress on the algal community: 1) the absolute abundance of algae in the sample; 2) the presence and relative abundance of indicator taxa in the sample; and 3) structural parameters of the diatom association, including number of taxa, Shannon-Weaver diversity ($\bar{d}$), and equitability (e) (Table 6). A fourth and important factor, which could not be assessed, is the physiological condition and growth rate of the algae that are present. Although all the samples appeared to contain at least some living algae, i.e., cells with protoplasts and pigments, it was impossible to determine whether they were growing vigor ously or just barely making a living.

The water quality requirements and pollution tolerances of the diatoms present were taken mainly from EPA (1974) and to a lesser extent from Patrick and Reimer (1966, 1976). Two diatom genera that are useful as indicators of nitrogen pollution and dissolved oxygen content are Nitzschia and Achnanthes, respectively. Overall, the low PRA's of the former and the high PRA's of the latter (Table 6) indicate that the waters sampled generally did not suffer from excessive organic nitrogen enrichment nor from chronically low dissolved oxygen levels. *Achnanthes* is also a "pioneer" genus in that it is usually one of the first algae to colonize a bare substrate following physical scouring or a massive die-off of other algae. Thus, at those stations where *Achnanthes* predominates (Tenmile Creek above and below Rimini; Spring Creek below Corbin and at Jefferson City), the flora can be considered as "immature" as a consequence of some recent past disturbance, physical or chemical.

In interpreting the results of these periphyton analyses, it is important to keep in mind that natural environmental factors other than sediment, metals, pH or dissolved solids from mining activities may act to stress periphyton communities and limit diversity. In the high elevation waters draining the granitic Boulder Batholith, low water temperatures and nutrient levels may be responsible in part for the generally sparse algal populations encountered. However, in certain cases discussed below, it is evident that stresses in addition to those that would naturally operate over this area are acting to more severely limit diversity and production.

Some general guidelines are available for interpreting the $\bar{d}$ and e values in Table 6. According to the EPA (1973) $\bar{d}$ values between 3 and 4 are typical of unpolluted waters and values below 1 usually indicate a significant stress on the aquatic community. An even more sensitive indicator of stress is equitability or e. In streams with healthy biotas, e generally falls between 0.6 and

0.8 while even slight degradation pushes equitability below 0.5. Presumably, values below 0.3 indicate even more severe stress. Diversity values of about 1 and below and equitability values of about 0.3 and below have been flagged in red in Table 6.

The sample interpretations that follow will be grouped according to drainage -- Tenmile, Little Blackfoot, Basin, and Prickly Pear -- and treated in a downstream order within each drainage. It is important to iterate that the periphyton samples reflect conditions that were in effect only on or shortly before the date of collection and in no way can be construed to reflect conditions that prevail seasonally or from year to year at a given site.

Tenmile Creek

Monitor Creek (0338A). This sample had a rather sparse flora both in terms of amount and kinds of algae. Achnanthes spp. accounted for about half of the diatom population. The $\bar{d}$ and e values indicate borderline conditions.

Upper Tenmile Creek (0339A). This sample had luxuriant and apparently healthy growths of both diatom and non-diatom algae. Although the number of diatom taxa was on the low side, the $\bar{d}$ and e values indicate favorable conditions. The dominant diatom taxon was Diatoma hiemale var. mesodon, which indicates cool flowing water with fairly low conductivity.

Banner Creek (0337A). The Banner Creek sample had an ample and diverse flora with no indication of even the slightest stress on the periphyton community.

Unnamed Creek near Red Mountain (0336A). This tributary to Banner Creek (enters below 0337A) had a moderately rich flora indicating no significant stress on the periphyton community.

Tenmile Creek above Rimini (0247A). This sample had only one species of non-diatom algae and a sparse diatom population dominated by *Achnanthes* spp. Diatom species diversity and equitability had the third lowest values among the 31 samples that were counted, and both values were under the threshold level indicating severe stress.

Tenmile Creek below Rimini (0246A). As with Tenmile Creek above Rimini, this sample had only one species of non-diatom algae and a depauperate diatom flora dominated by *Achnanthes* spp. There were six fewer taxa here than above Rimini and this was reflected in a correspondingly lower diversity index, which was the second lowest recorded for the entire study, unsurpassed only by the Spring Creek sample at Jefferson City (0315A). Conspicuous in this sample was a rusty brown colored floc. The periphyton community here appeared to be under even greater stress than the community above Rimini.

Minnehaha Creek (0335A). Diatoms were the only algae in this sample and they were very sparse. The dominant taxon, *Navicula minima*, is an indicator of waters with higher alkalinity and nutrient values. Diversity and equitability values were borderline.

Tenmile Creek at USGS Gaging Station (0127B). This sample had 4 genera of non-diatom algae in addition to an abundance of diatoms. The number of diatom taxa and the $\bar{d}$ and e values were all higher than corresponding values for the two Tenmile Creek samples from above and below Rimini. The dominant diatom was *Synedra minuscula*, which "prefers cool water". The algal flora here reflected a moderate amount of stress on the periphyton community.

*Colorado Gulch (0287A)*. Although diatoms were the only significant algae at this station, they were present in abundance and at comfortably high levels of diversity and equitability. The dominant taxon was *Navicula lanceolata*, which is an alkaliphilous, eutrophic species that "seems to prefer water of high mineral content".

*Grizzly Gulch (0286A)*. Diatoms were the only algae in this sample and they were sparse, dominated by *Achnanthes* spp. A borderline e value may endicate moderate stress on the periphyton community.

### Little Blackfoot River

*Ontario Creek (0291A)*. There was a considerable amount of algal material in the sample taken at this site. Although diatoms were more abundant than the other groups, only 10 diatom taxa were identified altogether and two of those taxa -- *Hannaea arcus* and *Diatoma hiemale* var. *mesodon* -- contributed 97.5 percent of the individual cells counted. Both these taxa indicate cool flowing waters and, although $\bar{d}$ and e values were both borderline, the low diatom diversity at this site is probably due to stenothermal and oligothermal conditions rather than to some man-caused stress.

Hat Creek (0290A). An abundance of Nostoc and a rich and equitably distributed diatom flora in the sample from this site all indicate the lack of any significant impact on the periphyton community.

Little Blackfoot River below Charter Oak Mines (0289A). An abundance of Ulothrix and a rich and equitably distributed diatom flora in the sample from this site all indicate no appreciable stress on the periphyton community from either natural or cultural sources.

Little Blackfoot River at Bridge (0288A). An abundance of Zygnema and Ulothrix and a rich and equitably distributed diatom flora in the sample collected at this site indicate no discernible stress on the periphyton community. (Diatom diversity was higher here than at any of the other stations sampled.)

Telegraph Creek above Lily-Boy (0314A). This sample included a rusty brown floc similar to that in 0246A. Although diatoms were sparse and the only algae present, they comprised a rich equitably distributed flora. Whatever impacts there may be at this site, they apparently have not affected the diatom flora. On the other hand, the diatom community sampled here was possibly not produced on the site but recently transported from unaffected reaches upstream.

Telegraph Creek below Lily-Boy (0313A). The brown floc was again conspicuous in the sample from this stream. Other than the very few, mostly dead diatom cells, the algal flora consisted of only one short filament of *Hormidium*, quite possibly drifted in from upstream. Diatoms were scarcer than in 0314A and too sparse to perform a proportional county. The total number of taxa *identified* was half the number *counted* in the sample from above the mine. Thus, the stress on the periphyton community at this point was apparently severe.

*Telegraph Creek below Hahn Creek (0312A)*. The sample from this location contained a richer than average non-diatom flora dominated by *Tolypothrix* and *Ulothrix*, and a reasonably diverse and equitably distributed diatom flora. Algal growth, as indicated by the sample, was healthy and luxuriant. Apparently, the stress that was evident at the next upstream station (0313A) was not felt at this point.

### Basin Creek

*Basin Creek at Winters Camp (0340A)*. The sample from this site contained more non-diatom genera (9) than any other. Diatom diversity and equitability were also sufficiently high to preclude any possibility of serious stress on the periphyton community.

### Prickly Pear Creek

*Prickly Pear Creek above Golconda Creek (0281A)*. Diatoms were abundant at this site and except for one trichome of *Anabaena*, they were the only algae present in the sample. In spite of the fact that the numbers of diatom taxa identified and counted were higher than average, $\bar{d}$ and e were marginal.

*Golconda Creek below Tailings (0280A)*. The sample from this site contained only a few filaments representing two genera of non-diatom algae and scattered diatom cells in 12 different taxa. The diatoms were too sparse for a proportional count, hence it is presumed that the periphyton community at this site had been under severe stress.

Spring Creek above Corbin (0306A). Algal material was generally abundant in this sample, but the senescent condition of the principal alga, Vaucheria, may indicate that the flora was at some stage of decline at the time of collection. However, $\bar{d}$ and e values were high, indicating that any stress, if present, had a negligible effect on the diatom association.

Spring Creek below Corbin (0316A). Diatoms were very sparse in the sample from this station and the $\bar{d}$ and e values were both below the threshold levels indicating significant impact. The diatom flora was dominated by the "pioneering" Achnanthes spp.

Spring Creek at Jefferson City (0315A). Diatoms were more common here than below Corbin, but the association had the fewest taxa counted (3) and the lowest diversity (0.061) of any sample. Again, Achnanthes spp. dominated the diatom flora. Only one genus of non-diatom algae (Entophysalis) was present. The periphyton community apparently was under extreme stress.

Warm Springs Creek (0282A). Diatoms were the only algae apparent in this sample and they were very sparse. However, a fairly large number of taxa were represented and $\bar{d}$ and e values were both high, possibly indicating no significant stress.

Clancy Creek above Kady Gulch (0307A). The sample from this point contained abundant algal material including two genera of blue-green algae. The dominant diatom species -- *Synedra ulna*, *Navicula lanceolata*, and *Cymbella minuta* -- indicate water with higher than average dissolved solids. Diversity and equitability were both relatively high and the community was probably not under stress.

*Clancy Creek below Kady Gulch (0308A)*. Both the diatom and non-diatom floras were more diverse below Kady Gulch than above, but equitability was somewhat lower. The high PRA values of *Navicula lamii* and *Nitzschia* spp. at this station indicate considerable nutrient (probably nitrogen) enrichment. However, there does not seem to be any significant effect on periphyton community structure.

*Quartz Creek (0311A)*. The Quartz Creek sample contained a meager amount of algal material. Diatoms were sparse and $\bar{d}$ and e values were marginal, indicating a moderate amount of stress on the periphyton community.

*Clancy Creek south of Clancy (0310A)*. This sample was dominated by *Hydrurus foetidus*, a common alga of cold headwater streams in the spring of the year. Diatoms were common, reasonably diverse and equitably distributed among the taxa. The rather high PRA for *Nitzschia* spp. indicates moderate nitrogen enrichment. Otherwise, no appreciable impact could be detected.

*Lump Gulch above Buffalo Creek (0283A)*. The upper Lump Gulch collection contained three genera of non-diatom algae. Diatoms were abundant and the PRA of *Nitzschia* spp. was higher in this sample (44.7%) than in any other, indicating significant nitrogen enrichment. Other than this, the diatom association appeared to be reasonably healthy.

Travis Creek (0285A). Diatoms were the only algae found in the sample from this stream but they were abundant. Travis Creek had the highest numbers of diatom taxa counted and identified of any stream sampled. Diversity and equitability values were also among the highest, indicating no appreciable stress on the periphyton community.

Buffalo Creek (0284A). Diatoms were sparse and ranked second behind the green alga Tetraspora in the sample from this stream. The dominant diatom taxon was Rhoicosphenia curvata, a species thriving in water of higher alkalinity and nutrient content. Diatom diversity and equitability were borderline.

Lump Gulch below tailings (0279A). This Lump Gulch sample contained diatoms in abundance as well as two genera of non-diatom algae. The diatom flora was fairly diverse and the cells were equitably distributed among the taxa. No significant impact was apparent.

Prickly Pear Creek below Clancy (0352A). This sample contained a rather normal association of algae with diatoms the most abundant. The major diatom taxa were Navicula minima and Surirella ovata, which indicated a higher dissolved solids content than most of the other waters that were sampled. Diatom diversity and equitability were about average.

# REFERENCES

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Patrick, R. and C. W. Reimer, 1966. The Diatoms of the United States. Volume I. The Academy of Natural Sciences, Philadelphia.

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Table 1. Sample locations, dates and assigned periphyton sample numbers.

| SAMPLE NO. | STATION LOCATION | DATE |
|---|---|---|
| 0127B | Tenmile Creek @ USGS Gaging Station | 4-06-77 |
| 0246A | Tenmile Creek below Rimini | 4-06-77 |
| 0247A | Tenmile Creek above Rimini | 4-06-77 |
| 0279A | Lump Gulch below tailings; 8N3W06BBB | 5-19-77 |
| 0280A | Golconda Creek below tailings; 7N3W17ACB | 5-18-77 |
| 0281A | Prickly Pear Creek above Golconda Creek; 7N3W17DCD | 5-18-77 |
| 0282A | Warm Springs Creek @ mouth; 8N3W16ABB | 5-18-77 |
| 0283A | Lump Gulch above Buffalo Creek; 8N4W03AD | 5-14-77 |
| 0284A | Buffalo Creek near mouth; 8N4W02BC | 5-14-77 |
| 0285A | Travis Creek near mouth; 9N4W33BD | 5-14-77 |
| 0286A | Grizzly Gulch below Glory Hole; 9N4W10BB | 5-14-77 |
| 0287A | Colorado Gulch @ road crossing; 9N5W12DDB | 5-20-77 |
| 0288A | Little Blackfoot River @ bridge; 9N6W19ACD | 5-20-77 |
| 0289A | Little Blackfoot River below Charter Oak Mines; 9N7W36ABA | 5-20-77 |
| 0290A | Hat Creek near mouth; 8N7W02AAA | 5-20-77 |
| 0291A | Ontario Creek near mouth; 8N7W12DAC | 5-20-77 |
| 0306A | Spring Creek @ bridge south of Corbin; 7N4W11ADB | 6-07-77 |
| 0307A | Clancy Creek above Kady Gulch; 7N4W5DBD | 6-07-77 |
| 0308A | Clancy Creek below Kady Gulch; 7N4W5ADD | 6-07-77 |
| 0310A | Clancy Creek @ bridge south of Clancy; 8N3W9BBA | 6-06-77 |
| 0311A | Quartz Creek near mouth; 8N4W28CCD | 6-06-77 |
| 0312A | Telegraph Creek below Hahn Creek; 9N6W29ACD | 6-01-77 |
| 0313A | Telegraph Creek below Lily-Boy; 8N6W15DAB | 6-01-77 |
| 0314A | Telegraph Creek above Lily-Boy; 8N6W15DAC | 6-01-77 |
| 0315A | Spring Creek @ Jefferson City; 7N3W6ACB | 6-09-77 |
| 0316A | Spring Creek below Corbin; 7N4W1CCD | 6-09-77 |
| 0335A | Minnehaha Creek near mouth; 9N5W29CAA | 7-13-77 |
| 0336A | Unnamed Creek near Red Mountain; 8N5W9DDA | 7-13-77 |
| 0337A | Banner Creek; 8N5W16BBB | 7-13-77 |
| 0338A | Monitor Creek; 8N5W18BBB | 7-13-77 |
| 0339A | Upper Tenmile Creek | 7-13-77 |
| 0340A | Basin Creek @ Winters Camp | 7-20-77 |
| 0352A | Prickly Pear Creek below Clancy; 8N3W4DC | 8-04-77 |

Table 2. Abundance of non-diatom algae and moss relative to diatoms as a group and to one another.

| SAMPLE NO. | ALGAL TAXA IN DESCENDING ORDER OF ABUNDANCE* |
|---|---|
| 0127B | D, Tribonema, Tetraspora, Phormidium, Ulothrix |
| 0246A | D, (Microthamnion ?) |
| 0247A | Pleurocapsa, D |
| 0279A | D, Closterium, Audouinella |
| 0280A | D, Phormidium, Tribonema |
| 0281A | D, Anabaena |
| 0282A | D |
| 0283A | D, Audouinella, Closterium, Oscillatoria |
| 0284A | Tetraspora, D |
| 0285A | D |
| 0286A | D |
| 0287A | D, Phormidium, Tribonema |
| 0288A | Zygnema, Ulothrix, D, Nostoc, Closterium, Anabaena |
| 0289A | Ulothrix, D, Closterium, Audouinella, Tribonema |
| 0290A | Nostoc, D |
| 0291A | D, Nostoc, Tribonema, Ulothrix, Audouinella |
| 0306A | Vaucheria, D, Tribonema, Spirogyra |
| 0307A | D, Phormidium, Oscillatoria |
| 0308A | D, Oscillatoria, Closterium, Hormidium, Hydrurus, Tribonema |
| 0310A | Hydrurus, D |
| 0311A | Unknown green, D, Oscillatoria |
| 0312A | Tolypothrix, Ulothrix, D, Nostoc, Audouinella, Zygnema, Closterium, Hormidium |
| 0313A | D, Hormidium |
| 0314A | D |
| 0315A | (Entophysalis ?), D |
| 0316A | (Entophysalis ?), D, Oscillatoria, Tribonema |
| 0335A | Moss, D |
| 0336A | Phormidium, D, Oscillatoria, Audouinella, Nostoc, Tetraspora |
| 0337A | Tribonema, D, Anabaena, Closterium |
| 0338A | D, Audouinella, Tribonema, Oscillatoria |
| 0339A | Zygnema, Tribonema, D, Audouinella, Closterium |
| 0340A | Zygnema, Ulothrix, D, Tribonema, Closterium, Anabaena, Chroococcus, Cosmarium, Mougeotia, Spirogyra |
| 0352A | D, Oscillatoria, Unknown blue-green, Cosmarium |

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*D = diatoms

Table 3. Overall frequency and weighted relative abundance of moss and algal taxa in samples from streams draining the northern Boulder Batholith.

| | FREQUENCY* (%) | WEIGHTED RELATIVE ABUNDANCE** (Range = 1 - 165) |
|---|---|---|
| BRYOPHYTA (mosses) | | |
| Unknown genus | 3.0 | 5 |
| CHLOROPHYTA (green algae) | | |
| Closterium | 27.0 | 12 |
| Cosmarium | 6.0 | 2 |
| Hormidium | 9.0 | 3 |
| (Microthamnion ?) | 3.0 | 4 |
| Mougeotia | 3.0 | 1 |
| Spirogyra | 6.0 | 2 |
| Tetraspora | 9.0 | 9 |
| Ulothrix | 18.0 | 20 |
| Unknown colonial coccoid | 3.0 | 5 |
| Zygnema | 12.0 | 16 |
| CHRYSOPHYTA (golden-brown algae) | | |
| Diatoms (all genera) | 100.0 | 119 |
| Hydrurus | 6.0 | 6 |
| Tribonema | 36.0 | 27 |
| Vaucheria | 3.0 | 5 |
| RHODOPHYTA (red algae) | | |
| Audouinella | 24.0 | 12 |
| CYANOPHYTA (blue-green algae) | | |
| Anabaena | 12.0 | 4 |
| Chroococcus | 3.0 | 1 |
| (Entophysalis ?) | 6.0 | 10 |
| Nostoc | 15.0 | 13 |
| Oscillatoria | 24.0 | 18 |
| Phormidium | 15.0 | 12 |
| Pleurocapsa | 3.0 | 5 |
| Tolypothrix | 3.0 | 5 |
| Unknown colonial coccoid | 3.0 | 3 |

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*Calculated as the number of samples in which each taxon was found as a percentage of 33 total samples

**Weighted as follows:

| Rank in Sample | Assigned Weight |
|---|---|
| 1 | 5 |
| 2 | 4 |
| 3 | 3 |
| 4 | 2 |
| Present but not ranked | 1 |

Table 4. Percent occurrence, percent mean relative abundance, and occurrence time abundance for diatom taxa in samples from streams draining the northern Boulder Batholith.

| | Occurence (%) | Mean RA (%) | Occurence-x-Abundance |
|---|---|---|---|
| Achnanthes affinis Grun. | 24.2 | 0.1 | 2.4 |
| A. clevei var. rostrata Hust. | 3.0 | <0.1 | -- |
| A. deflexa Reim. | 15.2 | 0.1 | 1.5 |
| A. exigua Grun. | 6.1 | 0.1 | 0.6 |
| A. lanceolata (Breb.) Grun. | 100.0 | 6.1 | 610.0 |
| A. lanceolata var. haynaldii (Istv.-Schaarsch) Cl. | 3.0 | <0.1 | -- |
| A. lapponica var. ninckei (Guerm & Mang) Reim. | 15.2 | 0.1 | 1.5 |
| A. linearis (W. Sm.) Grun. | 18.2 | 0.7 | 12.7 |
| A. linearis f. curta H. L. Sm. | 15.2 | 0.3 | 4.6 |
| A. marginulata Grun. | 9.1 | <0.1 | -- |
| A. microcephala (Kutz.) Grun. | 12.1 | <0.1 | -- |
| A. minutissima Kutz. | 97.0 | 23.2 | 2250.4 |
| A. pinnata Hust. | 15.2 | 0.1 | 1.5 |
| A. sp. | 21.2 | 0.5 | 10.6 |
| Amphipleura pellucida Kutz. | 3.0 | <0.1 | -- |
| Amphora ovalis var. affinis (Kutz.) V. H. ex DeT. | 3.0 | <0.1 | -- |
| A. ovalis var. pediculus (Kutz.) V. H. | 3.0 | <0.1 | -- |
| A. perpusilla (Grun.) Grun. | 27.3 | 0.1 | 2.7 |
| Anomoeoneis vitrea (Grun.) Ross comb. nov. | 3.0 | <0.1 | -- |
| Caloneis bacillum (Grun.) Cl. | 18.2 | <0.1 | -- |
| C. lewisii var. inflata (Schultze) Patr. | 3.0 | <0.1 | -- |
| C. ventricosa var. alpina (Cl.) Patr. comb. nov. | 3.0 | <0.1 | -- |
| C. sp. Cl. | 9.1 | <0.1 | -- |
| Cocconeis fluviatilis Wallace | 3.0 | <0.1 | -- |
| C. pediculus Ehr. | 3.0 | <0.1 | -- |
| C. placentula Ehr. | 66.7 | 2.2 | 146.7 |
| Cyclotella meneghiniana Kutz. | 6.1 | <0.1 | -- |
| C. sp. | 9.1 | <0.1 | -- |
| Cymatopleura solea (Breb. & Godey) W. Sm. | 6.1 | <0.1 | -- |
| Cymbella aspera (Ehr.) Herib. | 3.0 | <0.1 | -- |
| C. cistula(Ehr.) Kirchn. | 3.0 | <0.1 | -- |
| C. cymbiformis Ag. | 3.0 | <0.1 | -- |
| C. heteropleura var. subrostrata Cl. | 3.0 | <0.1 | -- |
| C. inaequalis (Ehr.) Rabh. | 6.1 | <0.1 | -- |
| C. mexicana (Ehr.) Cl. | 3.0 | <0.1 | -- |
| C. microcephala Grun. | 3.0 | <0.1 | -- |
| C. minuta Hilse ex Rabh. | 81.8 | 3.0 | 245.4 |

| | (%) | RA (%) | Abundance |
|---|---|---|---|
| Cymbella naviculiformis (Auersw. ex Rabenh.) Kirchn. | 15.2 | <0.1 | -- |
| C. sinuata Greg. | 57.6 | 0.4 | 23.0 |
| C. triangulum (Ehr.) Cl. | 3.0 | <0.1 | -- |
| C. sp. | 6.1 | <0.1 | -- |
| Denticula elegans Kutz. | 3.0 | <0.1 | -- |
| D. sp. | 6.1 | <0.1 | -- |
| Diatoma anceps (Ehr.) Kirchn. | 18.2 | 0.1 | 1.8 |
| D. hiemale var. mesodon (Ehr.) Grun. | 78.8 | 4.8 | 378.2 |
| D. vulgare Bory | 3.0 | <0.1 | -- |
| D. vulgare var. breve Grun. | 3.0 | <0.1 | -- |
| Diatomella belfouriana Grev. | 21.2 | <0.1 | -- |
| Diploneis oculata (Breb.) Cl. | 3.0 | <0.1 | -- |
| D. sp. Ehr. | 9.1 | <0.1 | -- |
| Epithemia sorex Kutz. | 6.1 | <0.1 | -- |
| E. turgida (Ehr.) Kutz. | 15.2 | 0.1 | 1.5 |
| E. sp. | 9.1 | <0.1 | -- |
| Eunotia perpusilla Grun. | 9.1 | 0.5 | 4.6 |
| E. tenella (Grun.) Cl. | 18.2 | 0.2 | 3.6 |
| E. sp. | 30.3 | 0.1 | 3.0 |
| Fragilaria bicapitata A. Mayer | 3.0 | <0.1 | -- |
| F. brevistriata Grun. | 12.1 | <0.1 | -- |
| F. brevistriata var. inflata (Pant.) Hust. | 15.2 | <0.1 | -- |
| F. capucina Desm. | 3.0 | <0.1 | -- |
| F. construens (Ehr.) Grun. | 18.2 | 0.1 | 1.8 |
| F. construens var. venter (Ehr.) Grun. | 48.5 | 0.7 | 34.0 |
| F. crotonensis Kitton. | 6.1 | <0.1 | -- |
| F. pinnata Ehr. | 6.1 | <0.1 | -- |
| F. vaucheriae (Kutz.) Peters | 78.8 | 3.8 | 299.4 |
| F. virescens Ralfs. | 12.1 | <0.1 | -- |
| F. sp. | 6.1 | 0.1 | 0.6 |
| Frustulia rhomboides (Ehr.) de Toni | 27.3 | 0.1 | 2.7 |
| F. rhomboides var. amphipleuroides (Grun.) Cl. | 3.0 | <0.1 | -- |
| F. rhomboides var. capitata (A. Mayer) Patr. | 3.0 | <0.1 | --- |
| F. vulgaris (Thwaites) De T. | 27.3 | 0.1 | 2.7 |
| F. vulgaris var. capitata Krasske | 3.0 | <0.1 | -- |
| Gomphonema acuminatum Ehr. | 3.0 | <0.1 | -- |
| G. affine Kutz. | 3.0 | <0.1 | -- |
| G. angustatum (Kutz.) Rabh. | 69.7 | 1.1 | 76.7 |

Table 4. Continued

| | Occurence (%) | Mean RA (%) | Occurence-Abundance |
|---|---|---|---|
| Gomphonema angustatum var. intermedia Grun. | 3.0 | 0.1 | 0.3 |
| G. clevei Fricke | 3.0 | < 0.1 | -- |
| G. dichotomum Kutz. | 39.4 | 0.6 | 23.6 |
| G. intricatum Kutz. | 9.1 | < 0.1 | -- |
| G. olivaceoides Hust. | 6.1 | 0.4 | 2.4 |
| G. parvulum (Kutz.) Kutz. | 27.3 | 0.4 | 10.9 |
| G. tenellum Kutz. | 6.1 | 0.1 | 0.6 |
| G. truncatum Ehr. | 3.0 | < 0.1 | -- |
| G. sp. | 24.2 | 0.2 | 4.8 |
| Gyrosigma acuminatum (Kutz.) Rabh. | 3.0 | < 0.1 | -- |
| Hannaea arcus (Ehr.) Patr. | 48.5 | 3.3 | 160.0 |
| Hantzschia amphioxys (Ehr.) Grun. | 36.4 | 0.1 | 3.6 |
| H. sp. Grunow | 3.0 | < 0.1 | -- |
| Melosira distans (Ehr.) Kutz. | 27.3 | 0.4 | 10.9 |
| M. granulata (Ehr.) Ralfs. | 3.0 | < 0.1 | -- |
| M. italica (Ehr.) Kutz. | 15.2 | 0.1 | 1.5 |
| M. roseana Rabh. | 6.1 | < 0.1 | -- |
| M. varians Ag. | 15.2 | < 0.1 | -- |
| M. sp. | 21.2 | 0.1 | 2.1 |
| Meridion circulare (Grev.) Ag. | 87.9 | 2.6 | 228.5 |
| M. circulare var. constrictum (Ralfs.) V. H. | 3.0 | < 0.1 | -- |
| Navicula americana Ehr. | 3.0 | < 0.1 | -- |
| N. arvensis Hust. | 57.6 | 1.3 | 74.9 |
| N. aurora Sov. | 3.0 | < 0.1 | -- |
| N. bacillum Ehr. | 3.0 | < 0.1 | -- |
| N. bicapitellata Hust. | 3.0 | < 0.1 | -- |
| N. cocconeiformis Greg. ex Grev. | 3.0 | < 0.1 | -- |
| N. convergens Patr. | 6.1 | < 0.1 | -- |
| N. cryptocephala Kutz. | 15.2 | 0.1 | 1.5 |
| N. cryptocephala var. veneta (Kutz.) Rabh. | 60.6 | 1.0 | 60.6 |
| N. cuspidata (Kutz.) Kutz. | 3.0 | < 0.1 | -- |
| N. elginensis (Greg.) Ralfs. | 9.1 | < 0.1 | -- |
| N. exigua var. capitata Patr. | 3.0 | < 0.1 | -- |
| N. festiva Krasske | 9.1 | < 0.1 | -- |
| N. fragilarioides Krasske | 3.0 | < 0.1 | -- |
| N. gottlandica Grun. | 6.1 | < 0.1 | -- |
| N. graciloides A. Mayer | 12.1 | < 0.1 | -- |
| N. keeleyi Patr. | 3.0 | < 0.1 | -- |

Table 4. Continued

| | Occurence (%) | Mean RA (%) | Occurence-Abundance |
|---|---|---|---|
| Navicula lamii Manguin | 30.3 | 1.0 | 30.3 |
| N. lanceolata (Ag.) Kutz. | 36.4 | 3.6 | 131.0 |
| N. laterostrata Hust. | 3.0 | $<0.1$ | -- |
| N. minima Grun. | 39.4 | 3.2 | 126.1 |
| N. mutica Kutz. | 21.2 | 0.1 | 2.1 |
| N. mutica var. undulata (Hilse) Grun. | 3.0 | $<0.1$ | -- |
| N. notha Wallace | 9.1 | 0.2 | 1.8 |
| N. pelliculosa (Breb. ex Kutz.) Hilse | 3.0 | $<0.1$ | -- |
| N. perparva Hustedt | 3.0 | $<0.1$ | -- |
| N. perpusilla (Kutz.) Grun. | 3.0 | $<0.1$ | -- |
| N. pupula Kutz. | 21.2 | 0.1 | 2.1 |
| N. rhynchocephala Kutz. | 12.1 | $<0.1$ | -- |
| N. rotaeana (Rabh.) Grun. | 6.1 | 0.1 | 0.6 |
| N. secreta var. apiculata Patr. | 42.4 | 0.7 | 29.7 |
| N. seminulum Grun. | 9.1 | $<0.1$ | -- |
| N. tripunctata (O. F. Mull.) Bory | 18.2 | 0.4 | 7.3 |
| N. ventralis var. chilensis Krasske | 3.0 | $<0.1$ | -- |
| N. viridula var. rostellata (Kutz?) Cl. | 3.0 | $<0.1$ | -- |
| N. sp. | 45.4 | 0.2 | 9.1 |
| Neidium affine (Ehr.) Pfitz. | 6.1 | $<0.1$ | -- |
| N. affine var. longiceps (Greg.) Cl. | 3.0 | $<0.1$ | -- |
| N. binode (Ehr.) Hust. | 3.0 | $<0.1$ | -- |
| N. bisulcatum (Lagerst.) A. Cl. | 6.1 | $<0.1$ | -- |
| N. iridis (Ehr.) Cl. | 6.1 | $<0.1$ | -- |
| N. iridis var. ampliatum (Ehr.) Cl. | 3.0 | $<0.1$ | -- |
| Nitzschia acicularis (Kutz.) W. Sm. | 21.2 | 0.2 | 4.2 |
| N. acuta Hantz. | 3.0 | $<0.1$ | -- |
| N. amphibia Grun. | 3.0 | $<0.1$ | -- |
| N. capitellata Hust. | 9.1 | 0.1 | 0.9 |
| N. communis Rabh. | 36.4 | 0.3 | 10.9 |
| N. dissipata (Kutz.) Grun. | 69.7 | 1.3 | 90.6 |
| N. epiphytica O. Mull. | 9.1 | $<0.1$ | -- |
| N. fonticola Grun. | 3.0 | $<0.1$ | -- |
| N. frustulum Kutz. | 57.6 | 0.5 | 28.8 |
| N. frustulum var. subsalina Hust. | 6.1 | 0.1 | 0.6 |
| N. ignorata Krasske | 3.0 | $<0.1$ | -- |
| N. kutzingiana Hilse | 24.2 | 0.1 | 2.4 |
| N. linearis (Ag. ex. W. Sm.) W. Sm. | 66.7 | 1.8 | 120.1 |

|  | (%) | RA (%) | Abundance |
|---|---|---|---|
| Nitzschia palea (Kutz.) W. Sm. | 69.7 | 1.2 | 83.6 |
| N. paleacea Grun. | 63.6 | 3.6 | 229.0 |
| N. recta Hantz. | 15.2 | < 0.1 | -- |
| N. sigmoidea (Ehr.) W. Sm. | 3.0 | < 0.1 | -- |
| N. sp. | 21.2 | 0.1 | 2.1 |
| Pinnularia acuminata var. instabilis (A. S.) Patr. | 3.0 | < 0.1 | -- |
| P. appendiculata (Ag.) Cl. | 9.1 | < 0.1 | -- |
| P. borealis Ehr. | 30.3 | 0.1 | 3.0 |
| P. borealis var. rectangularis Carlson | 3.0 | < 0.1 | -- |
| P. braunii var. amphicephala (A. Mayer) Hust. | 3.0 | < 0.1 | -- |
| P. divergentissima (Grun.) Cl. | 6.1 | < 0.1 | -- |
| P. hilseana Jan. | 3.0 | < 0.1 | -- |
| P. intermedia (Lagst.) Cl. | 3.0 | < 0.1 | -- |
| P. maior (Kutz.) Rabh. | 6.1 | < 0.1 | -- |
| P. mesolepta var. angusta Cl. | 6.1 | < 0.1 | -- |
| P. stomatophora (Grun.) Cl. | 3.0 | < 0.1 | -- |
| P. subcapitata Greg. | 3.0 | < 0.1 | -- |
| P. subcapitata var. paucistriata (Grun.) Cl. | 3.0 | < 0.1 | -- |
| P. viridis var. commutata (Grun.) Cl. | 3.0 | < 0.1 | -- |
| P. sp. | 48.5 | 0.4 | 19.4 |
| Rhoicosphenia curvata (Kutz.) Grun. | 48.5 | 2.1 | 101.8 |
| Rhopalodia gibba (Ehr.) O. Mull. | 15.2 | < 0.1 | -- |
| R. gibba var. ventricosa (Kutz.) H. & M. Perag. | 6.1 | < 0.1 | -- |
| R. gibberula (Ehr.) O. Mull. | 3.0 | < 0.1 | -- |
| R, gibberula var. vanheurckii O. Mull. | 3.0 | < 0.1 | -- |
| R. musculus (Kutz.) O. Mull. | 6.1 | < 0.1 | -- |
| R. parallela (Grun.) O. Mull. | 3.0 | < 0.1 | -- |
| Stauroneis acuta W. Sm. | 3.0 | < 0.1 | -- |
| S. anceps Ehr. | 3.0 | < 0.1 | -- |
| S. anceps f. gracilis Rabh. | 3.0 | < 0.1 | -- |
| S. anceps f. linearis (Ehr.) Hust. | 6.1 | < 0.1 | -- |
| S. kriegeri Patr. | 6.1 | < 0.1 | -- |
| S. phoenicenteron (Nitz.) Ehr. | 6.1 | < 0.1 | -- |
| S. phoenicenteron f. gracilis (Ehr.) Hust. | 6.1 | < 0.1 | -- |
| S. smithii Grun. | 6.1 | < 0.1 | -- |
| Stenopterobia intermedia (Lewis) | 3.0 | < 0.1 | -- |
| Stephanodiscus astraea (Ehr.) Grun. | 3.0 | < 0.1 | -- |
| Surirella angustata Kutz. | 63.6 | 0.7 | 44.5 |

|  | (%) | RA (%) | Abundance |
|---|---|---|---|
| Surirella biseriata Breb. | 3.0 | <0.1 | -- |
| S. biseriata var. bifron (Ehr.) Hust. | 3.0 | <0.1 | -- |
| S. linearis W. Sm. | 6.1 | <0.1 | -- |
| S. linearis var. constricta (Ehr.) Grun. | 6.1 | <0.1 | -- |
| S. linearis var. helvetica (Brun.) Meister | 3.0 | <0.1 | -- |
| S. ovata Kutz. | 42.4 | 1.9 | 80.6 |
| S. sp. | 3.0 | <0.1 | -- |
| Synedra acus Kutz. | 6.1 | <0.1 | -- |
| S. delicatissima W. Sm. | 3.0 | <0.1 | -- |
| S. fasciculata var. truncata (Grev.) Patr. | 3.0 | <0.1 | -- |
| S. incisa Boyer | 6.1 | <0.1 | -- |
| S. minuscula Grun. | 66.7 | 6.7 | 446.9 |
| S. parasitica (W. Sm.) Hust. | 3.0 | <0.1 | -- |
| S. rumpens Kutz. | 6.1 | <0.1 | -- |
| S. rumpens var. familiaris (Kutz.) Hust. | 6.1 | <0.1 | -- |
| S. rumpens var. scotica Grun. | 3.0 | 0.4 | 1.2 |
| S. ulna | 54.6 | 2.3 | 125.6 |
| S. ulna var. ramesi (Herib.) Hust. | 3.0 | <0.1 | -- |
| S. sp. | 12.1 | <0.1 | -- |
| Tabellaria flocculosa (Roth) Kutz. | 3.0 | <0.1 | -- |

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* At least 6 cells must be counted for any given taxon before it will register 0.1 percent mean relative abundance.

Table 5. Percent relative abundance of "major taxa" in each of the 31 samples counted.

| | 0127B | 0246A | 0247A | 0279A | 0280A | 0281A | 0282A |
|---|---|---|---|---|---|---|---|
| Achnanthes lanceolata | 2.3 | 0.3 | 0.3 | 10.0 | x | 21.9 | 22.7 |
| A. linearis | | 11.8 | 3.9 | | | | |
| A. minutissima | 9.9 | 86.8 | 83.9 | 9.7 | x | 7.8 | 8.4 |
| A. sp. | | | | | | | 0.6+t (2) |
| Cocconeis placentula | t | | | 4.9 | x | 8.1 | 2.5 |
| Cymbella minuta | | | | 6.1 | x | 5.0 | 1.6 |
| Diatoma hiemale var. mesodon | 3.3 | t | 2.9 | | x | 7.5 | 2.2 |
| Fragilaria vaucheriae | | | | 0.9 | x | 11.9 | 3.1 |
| Gomphonema olivaceoides | | | | | | | |
| Hannaea arcus | | t | 1.0 | t | | 2.2 | 1.2 |
| Meridion circulare | 6.6 | | | | x | 0.9 | 0.3 |
| Navicula arvensis | t | | | 0.6 | | t | 2.2 |
| N. lamii | | | | t | | | |
| N. lanceolata | | | | 22.2 | | 5.9 | 0.3 |
| N. minima | | | | 1.2 | | 0.9 | 18.6 |
| Nitzschia linearis | | | | 7.6 | | 1.6 | 3.4 |
| N. palea | 0.3 | | | 2.4 | x | 0.9 | 2.8 |
| N. paleacea | | | | 0.9 | | 0.3 | 0.6 |
| Rhocosphenia curvata | | | | 1.8 | | 1.2 | 1.6 |
| Surirella ovata | | | | 11.2 | | t | 4.0 |
| Synedra minuscula | 64.1 | | 0.6 | 0.3 | | 1.6 | 0.9 |
| S. rumpens var. scotica | 11.5 | | | | | | |
| S. ulna | | | | 4.3 | | 1.9 | 0.3 |

Table 5. Continued

| | 0283A | 0284A | 0285A | 0286A | 0287A | 0288A | 0289A |
|---|---|---|---|---|---|---|---|
| Achnanthes lanceolata | 1.9 | 3.6 | 14.6 | 6.0 | 9.2 | 1.8 | 3.4 |
| A. linearis | | | | | | | |
| A. minutissima | 13.6 | 1.8 | 1.6 | 60.1 | 17.6 | 11.4 | 15.7 |
| A. sp. | | | | | | 0.6 | |
| Cocconeis placentula | 0.6 | 31.6 | 0.3 | 3.6 | 3.6 | 0.6 | 0.6 |
| Cymbella minuta | 15.8 | | | t | t | 8.6 | 0.6 |
| Diatoma hiemale var. mesodon | | 0.3 | | | 2.0 | 8.3 | 13.7 |
| Fragilaria vaucheriae | 3.8 | 0.9 | 4.8 | 0.3 | 3.6 | 4.9 | 10.6 |
| Gomphonema olivaceoides | | | | | | 0.9 | 11.4 |
| Hannaea arcus | 0.6 | | | | 0.3 (?) | 3.1 | 7.1 |
| Meridion circulare | t | 0.3 | 2.5 | 2.7 | 0.8 | 0.6 | 1.4 |
| Navicula arvensis | 1.3 | | 1.3 | 2.1 | | 4.0 | |
| N. lamii | | | 0.3 | | | 0.3 | |
| N. lanceolata | 0.6 | 2.1 | 32.1 | 3.0 | 36.5 | 0.3 | |
| N. minima | t | | | 0.9 | | | t |
| Nitzschia linearis | 0.6 | 1.8 | 4.1 | 1.5 | 1.1 | 0.3 | 0.3 |
| N. palea | 4.4 | | 2.2 | 0.6 | 0.6 | 14.1 | 0.3 |
| N. paleacea | 34.7 | 0.6 | 0.6 | 0.3 | | 1.5 | 0.3 |
| Rhocosphenia curvata | t | 48.7 | 0.6 | 2.7 | 2.2 | 1.2 | |
| Surirella ovata | 1.9 | 0.9 | 0.6 | 0.6 | | | |
| Synedra minuscula | | | 0.6 | 0.3 | | 8.6 | |
| S. rumpens var. scotica | | | | | | | |
| S. ulna | 14.2 | 0.3 | | 0.6 | | 3.4 | 1.1 |

Table 5. Continued

| | 0290A | 0291A | 0306A | 0307A | 0308A | 0310A | 0311A |
|---|---|---|---|---|---|---|---|
| Achnanthes lanceolata | 7.5 | 0.6 | 17.4 | 3.9 | 18.8 | 2.8 | 0.9 |
| A. linearis | | | | | | | |
| A. minutissima | 21.5 | | 3.9 | 1.9 | 3.8 | 8.0 | 68.5 |
| A. sp. | | | | | | | |
| Cocconeis placentula | 7.2 | | t | t | t | | 7.2 |
| Cymbella minuta | 0.6 | 0.6 | 6.4 | 14.2 | 2.9 | 3.1 | 1.8 |
| Diatoma hiemale var. mesodon | 3.6 | 23.5 | 0.6 | 0.3 | | 1.8 | |
| Fragilaria vaucheriae | 3.9 | t | 16.4 | 3.6 | 0.6 | 14.4 | 2.1 |
| Gomphonema olivaceoides | | | | | | | |
| Hannaea arcus | | 74.0 | | | | | |
| Meridion circulare | 2.7 | 0.6 | 2.9 | 2.9 | 2.9 | | 0.9 |
| Navicula arvensis | 5.4 | | 3.2 | 0.6 | 2.6 | 17.1 | |
| N. lamii | 1.8 | | 4.2 | | 15.6 | 2.4 | 2.4 |
| N. lanceolata | | | | 15.2 | t | | 0.3 |
| N. minima | | | 0.6 | 1.0 | t | t | t |
| Nitzschia linearis | 0.6 | | 12.3 | 5.8 | 1.3 | 8.6 | |
| N. palea | 1.2 | | 5.2 | 1.3 | 0.3 | 0.3 | |
| N. paleacea | 10.8 | | 6.4 | 5.2 | 26.8 | 22.9 | |
| Rhocosphenia curvata | 2/4 | | | 0.6 | | | 3.9 |
| Surirella ovata | | | 2.3 | 1.3 | 1.9 | 10.1 | |
| Synedra minuscula | | 0.3 | 1.3 | | 1.6 | 0.6 | |
| S. rumpens var. scotica | | | | | | | |
| S. ulna | 10.4 | | 0.3 | 30.1 | t | | 1.5 |

Table 5. Continued

| | 0312A | 0313A | 0314A | 0315A | 0316A | 0335A | 0336A |
|---|---|---|---|---|---|---|---|
| Achnanthes lanceolata | 4.0 | x | 14.9 | 0.3 | 2.1 | 3.1 | 11.8 |
| A. linearis | | | | | | | |
| A. minutissima | 11.2 | x | 1.6 | 99.4 | 87.7 | 21.0 | 37.8 |
| A. sp. | | | | | | 0.3 | 12.1 |
| Cocconeis placentula | 1.4 | | 0.3 | | 0.3 | t | |
| Cymbella minuta | 0.6 | x | 2.9 | t | t | | 2.5 |
| Diatoma hiemale var. mesodon | 32.7 | x | 0.6 | | t | 8.4 | 2.8 |
| Fragilaria vaucheriae | 14.3 | | | 0.3 | 1.5 | | |
| Gomphonema olivaceoides | | | | | | | |
| Hannaea arcus | 5.7 | x | | t | | | t |
| Meridion circulare | 3.4 | x | 26.0 | t | t | 0.3 | 14.9 |
| Navicula arvensis | 0.3 | | | t | 0.3 | | |
| N. lamii | | | | | 0.3 | | |
| N. lanceolata | | | | | | | |
| N. minima | | | | | | 62.8 | |
| Nitzschia linearis | t | | 0.6 | t | 0.3 | t | |
| N. palea | | x | | | 0.3 | | 0.9 |
| N. paleacea | 1.4 | | | t | 1.2 | | |
| Rhocosphenia curvata | 0.3 | | 0.3 | | | 0.3 | |
| Surirella ovata | | | | t | 0.3 | | |
| Synedra minuscula | 8.6 | | 1.6 | | 0.9 | 0.3 | |
| S. rumpens var. scotica | | | | | | | |
| S. ulna | 2.6 | | | | 0.3 | | |

Table 5. Concluded

| | 0337A | 0338A | 0339A | 0340A | 0352A |
|---|---|---|---|---|---|
| Achnanthes lanceolata | 0.9 | 0.3 | 6.0 | 3.6 | 3.5 |
| A. linearis | 0.3 | 5.6 | 0.9 | | |
| A. minutissima | 1.5 | 39.4 | 10.1 | 7.0 | 12.7 |
| A. sp. | | 1.8 | 1.6 | 0.6 | |
| Cocconeis placentula | | | | 0.9 | |
| Cymbella minuta | 2.7 | 7.4 | 11.6 | 1.2 | 2.6 |
| Diatoma hiemale var. mesodon | 7.9 | 2.1 | 31.1 | 1.2 | 0.6 |
| Fragilaria vaucheriae | 15.8 | 1.8 | 5.0 | 0.6 | 0.3 |
| Gomphonema olivaceoides | | | | | |
| Hannaea arcus | 13.9 | | | | t |
| Meridion circulare | 5.8 | 0.6 | 4.7 | 1.5 | 0.3 |
| Navicula arvensis | 0.3 | | | 0.3 | 1.6 |
| N. lamii | | | | | 0.3 |
| N. lanceolata | | | | | |
| N. minima | | | | | 20.7 |
| Nitzschia linearis | t | | | | 6.7 |
| N. palea | 0.6 | 0.3 | | 1.8 | t |
| N. paleacea | 1.8 | t | | 3.3 | 0.3 |
| Rhocosphenia curvata | | | | 0.6 | |
| Surirella ovata | | | | | 27.1 |
| Synedra minuscula | 17.6 | 26.8 | 10.7 | 56.4 | 4.8 |
| S. rumpens var. scotica | | | | | |
| S. ulna | | | 0.3 | 0.6 | 2.6 |

Selected diatom community parameters.

| | Total Taxa | Taxa Counted | Cells Counted | $\bar{d}$ | e | PRA Nitzschia | PRA Achnanthes |
|---|---|---|---|---|---|---|---|
| 0127B | 19 | 11 | 304 | 1.822 | 0.45 | 0.3 | 12.2 |
| 0246A | 10 | 5 | 348 | 0.649 | 0.40 | | 99.8 |
| 0247A | 16 | 8 | 311 | 0.976 | 0.25 | t | 95.2 |
| 0279A | 34 | 26 | 329 | 3.789 | 0.77 | 15.1 | 19.7 |
| 0280A | 12 | | | | | | |
| 0281A | 49 | 34 | 320 | 1.766 | 0.12 | 5.9 | 30.0 |
| 0282A | 49 | 39 | 322 | 4.088 | 0.64 | 9.5 | 33.9 |
| 0283A | 28 | 17 | 317 | 2.896 | 0.59 | 44.7 | 15.5 |
| 0284A | 28 | 24 | 335 | 2.262 | 0.25 | 3.3 | 5.4 |
| 0285A | 62 | 49 | 315 | 4.030 | 0.49 | 12.3 | 17.5 |
| 0286A | 38 | 29 | 336 | 2.630 | 0.31 | 6.3 | 67.6 |
| 0287A | 32 | 23 | 359 | 3.173 | 0.57 | 3.4 | 27.4 |
| 0288A | 48 | 44 | 326 | 4.464 | 0.75 | 22.9 | 14.1 |
| 0289A | 45 | 37 | 350 | 3.851 | 0.57 | 2.1 | 19.1 |
| 0290A | 30 | 28 | 335 | 3.930 | 0.79 | 16.5 | 29.0 |
| 0291A | 10 | 7 | 315 | 1.004 | 0.29 | | 0.6 |
| 0306A | 41 | 33 | 310 | 3.971 | 0.70 | 29.7 | 21.9 |
| 0307A | 31 | 26 | 309 | 3.446 | 0.62 | 18.1 | 5.8 |
| 0308A | 55 | 34 | 314 | 3.558 | 0.50 | 36.9 | 22.9 |
| 0310A | 33 | 24 | 327 | 3.383 | 0.62 | 35.8 | 11.4 |
| 0311A | 22 | 20 | 333 | 2.054 | 0.25 | 4.5 | 69.7 |
| 0312A | 42 | 32 | 349 | 3.454 | 0.50 | 5.7 | 15.8 |
| 0313A | 24 | | | | | | |
| 0314A | 55 | 48 | 315 | 3.970 | 0.48 | 5.3 | 17.7 |
| 0315A | 13 | 3 | 322 | 0.061 | 0.33 | | 99.7 |
| 0316A | 26 | 19 | 333 | 0.996 | 0.11 | 3.6 | 90.1 |
| 0335A | 32 | 14 | 323 | 1.694 | 0.29 | t | 24.4 |
| 0336A | 37 | 27 | 323 | 3.108 | 0.44 | 3.0 | 64.5 |
| 0337A | 49 | 44 | 330 | 4.075 | 0.57 | 9.0 | 3.0 |
| 0338A | 34 | 29 | 340 | 2.876 | 0.34 | 0.9 | 49.5 |
| 0339A | 29 | 24 | 318 | 3.446 | 0.67 | 0.9 | 20.2 |
| 0340A | 45 | 36 | 330 | 2.954 | 0.39 | 8.4 | 11.8 |
| 0352A | 28 | 22 | 314 | 3.250 | 0.64 | 7.0 | 16.5 |

**TO** : WATER QUALITY BUREAU FIELD PERSONNEL **DATE:** June 20, 1977

**FROM** : LOREN BAHLS

**SUBJECT** : PROCEDURE FOR COLLECTING COMPOSITE PERIPHYTON SAMPLES FROM NATURAL SUBSTRATES

Periphyton consists of the assemblage of plants and animals, mostly microscopic, living attached to or immediately upon the bottom of a body of water. The plants in this community of organisms are responsible for the greater share of primary production in most Montana rivers and streams. These plants are usually algae, which often make the river or stream bottom slippery and slimy to the touch. Each kind of plant in the periphyton has specific environmental needs, allowing for their use--singly or collectively--as biological monitors of water quality.

The object in sampling periphyton from natural substrates is to obtain a collection of algae that is representative of the community from which it came. The algae should be present in the sample roughly in the same proportion as they exist in the stream. Different substrates--rock, silt, logs, higher aquatic plants--should be sampled in proportion to their importance as a substrate at a given station. Substrates exposed to different current velocities, depths, and shading should also be sampled, again roughly in proportion to the extent these conditions prevail at a site. (For example, if a section of stream to be sampled is 80 percent riffle and 20 percent pool, about 80 percent of the sample should come from riffles.)

Only a minimum of equipment is required: pocket knife, small bottles or vials with screw caps, labels, pen or pencil, and preservative. The following steps are recommended:

1. Fill sample container about half full of stream water, making sure the container is clean.

2. Collect individual filaments and colonies of macroscopic algae in proportion to their abundance relative one to another.

3. Carefully clean knife.

4. Scrape natural substrates as outlined in the previous paragraph.

5. Add preservative (to retard bacterial growths), cap, and label.

Generally, only a few milliliters of periphyton make a sufficient sample. Most any available preservative is acceptable, including formalin (10% formaldehyde), Lugol's (IKI), and ethanol. Lugol's, available from Abe Horpestad or myself, is preferred. You need add only enough to give a permanent red tint to the sample. No preservative is necessary if samples are delivered to me within 24 hours after collection.

The sample should be labelled clearly with the date, the name of the water sampled, a general description of the sampling station, e.g., Tenmile Creek at USGS gaging station, the county in which the station is located and/or an accurate legal description including range, township, section, and tract. Completion of a computer data card is not necessary unless water samples for chemical analyses are collected at the same time. Along with the samples, the sampler should include a note with the sampler's name, the name of the project (if any), and the desired deadline for completion of analyses and an interpretive report.

In addition to projects for which biological periphyton analyses have been budgeted, I would welcome samples from any uncollected waters in Montana. These samples will be used to determine the distribution and water quality relationships of individual diatom taxa in the state. If you are travelling, please check the map in my office. It shows where periphyton collections have already been made. If you plan on visiting an unsampled area, I will gladly furnish you with bottles, labels, and preservative. If you got the time, I've got the gear.

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CONCENTRATION LISTED KNOWN NOT TO CAUSE ADVERSE EFFECTS UNLESS SPECIFIED*

# ELEMENTS

| | [illegible] | [illegible] | IRRIGATION LONG TERM | FRESHWATER AQUATIC LIFE | | US AVERAGE CONCENTRATION | MONTANA | |
|---|---|---|---|---|---|---|---|---|
| | | | | effect | no effect | | AVERAGE | RANGE |
| Aluminum (Al) | 1-5[a131] | 5[d309] | 1.0[a130] | .07[a130] | .05[d179] | .074[c8] | .2 | <.1-2.8 |
| Antimony (Sb) | --[a139] | | | 3.5[a139] | | | | |
| Arsenic (As) | .05[e] | .2[d310] | .10[d339] | 1.1[a141] | 1.0[a141] | .043[c8] | .025 | <.001-.090 |
| Barium (Ba) | 1.0[d57] | | 1.0[k13] | 12[a143] | 5[a142] | | <.1 | <.1-.4 |
| Beryllium (Be) | --[a148] | --[a145] | .10[d339] | .15[a146] | .011[a146] | .0002[c8] | <.005 | <.005-.01 |
| Boron (B) | 5[d59] | 5.0[d310] | .75[d339] | 5000[a148] | 2000[a148] | .101[c8] | .1 | <.1-13 |
| Bromine (Br) | --[k119] | | | 10[a148] | 1.0[a148] | | | |
| Cadmium (Cd) | .01[d60] | .05[d311] | .01[d339] | .0005[d180] | .0004[d180] | .0095[c8] | .006 | <.002-.005 |
| Calcium (Ca) | | 1000[a151] | | | | 57.1[d306] | 65.3 | 15-216 |
| Cerium (Ce) | --[a157] | | | .14[a157] | | | | |
| Chlorine (Cl) | 2[a161] | | 3.0[a162] | .03[a162] | .002[035] | | | |
| Chromium (Cr) | .05[e] | 1.0[d311] | .10[d339] | 1.2[a165] | .05[d180] | .0097[c8] | <.02 | <.02-.02 |
| Cobalt (Co) | --[a166] | 1.0[d311] | .05[d339] | 10[a167] | 1.0[a167] | .001[d306] | <.03 | <.03-.03 |
| Copper (Cu) | 1.0[a169] | .5[d312] | .1[a171] | .025[a171] | .02[a171] | .0138[d306] | .01 | <.01-.23 |
| Gold (Au) | --[a193] | | | .40[a193] | | | | |
| Iodine (I) | | | | | | .046[d306] | | |
| Iron (Fe) | .3[a204] | --[g136] | 5.0[d339] | .2[a203] | | .044[d306] | <.05 | <.05-.29 |
| Lanthanum (La) | --[a206] | --[a206] | | .15[a206] | | | | |
| Lead (Pb) | .05[e] | .1[d313] | 5.0[d339] | .1[a208] | .03[d181] | .023[c8] | <.05 | <.05-.07 |
| Lithium (Li) | 5[a210] | | .075[d339] | | | | | |
| Magnesium (Mg) | 30-125[a211] | 500[a211] | 24[a211] | 300[a212] | | 14.3[d306] | 17 | <1-175 |
| Manganese (Mn) | .05[a215] | 10[a215] | .2[d339] | 2.2[a215] | 1.0[a215] | .029[d306] | <.01 | <.01-.10 |
| Mercury (Hg) | .002[e] | .01[d314] | | .008[a218] | .00005[d174] | | | |
| Molybdenum (Mo) | | --[g136] | .01[d339] | 70[a221] | | .068[c8] | .030 | <.001-.299 |
| Nickel (Ni) | 1.0[d482] | | .20[d339] | 5[d181] | | .019[c8] | <.02 | <.02-.03 |
| Oxygen ($O_2$) | *≥4[g20] | | | | --[d131] | | 10.2 | 7.4-22 |
| Palladium (Pd) | | | | 7[234] | | | | |
| Potassium (K) | 340[a243] | | | 50[a243] | | 4.3[d306] | 3.1 | <.1-13 |
| Radium (Ra) | --[a250] | | | | | $.05\times10^{-5}$[a250] | | |
| Rubidium (Rb) | | | | 14[a253] | | | | |
| Selenium (Se) | .01[e] | .05[d316] | .02[d339] | 2[a254] | | .000016[d306] | .004 | <.002-.014 |
| Silver (Ag) | .05[e] | --[a254] | .05[k19] | .003[a257] | | .0026[c8] | <.05 | |
| Sodium (Na) | | 2000[g137] | | 500[a259] | | 55.1[d306] | 40.6 | 1.0-530 |
| Strontium (Sr) | --[a274] | --[a274] | --[a274] | | | .22[c8] | .2 | <.1-1.0 |
| Sulfur (S) | | | | 10[a278] | | | | |
| Thallium (Tl) | | | | | .05[d256] | | | |
| Thorium (Th) | | | | .4[a286] | | | | |
| Tin (Sn) | --[a286] | --[a286] | 40[a286] | 6.0[a287] | 1.2[a287] | | | |
| Titanium (Ti) | --[a287] | --[a287] | 12[a287] | 2.0[a287] | | | | |
| Tungsten (W) | | | | 110[a290] | | | | |
| Uranium (U) | .5-1.0[a291] | --[a291] | | 2.8[a292] | | | | |
| Vanadium (V) | --[a292] | .1[d316] | .10[d339] | 4.8[a292] | | .04[c8] | .018 | <.001-.16 |
| Zinc (Zn) | 5[a294] | 25[d317] | 2.0[d339] | .01[a295] | .003[a296] | | .03 | <.01-.17 |
| Zirconium (Zr) | | --[a297] | | 14[a298] | | .052[d306] | | |

# PHYISICAL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Color (units) | 75[d63] | | | | | | 7 | <5-45 |
| Conductance (umho/cm) | | | 750[d335] | | | | 531 | 128-2269 |
| pH | 5.0-9.0[d80] | | 4.5-9.0[d332] | | 6.5-8.5[g41] | | 8.1 | 6.7-9.4 |
| Residue (Nonfilterable) (TSS)[1] | [a280] | | --[d332] | | 25[d129] | | | |
| Residue (filterable) (TDS)[2] | 500[a89] | 2860[g134] | 500[d335] | | | | 330 | 82-2361 |
| Temperature | --[d89] | | | | --[d151] | | 9.5 | 0-27 |
| Turbidity (Units) | 1-5[e] | | | | --[g74] | | 325 | 7.5-22000 |
| %Gas Saturation | | | | | 110%[d139] | | | |

# BIOLOGICAL

CONCENTRATION EXPRESSED AS ORGANISMS PER 100 MILLITERS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Total Coliforms | 1[e] | | | | 70[g37] | | 235 | 0-4800 |
| Fecal Coliforms | | | | | | | 181 | 0-7000 |

# COMPOUNDS

| | [illegible] | STOCK | IRRIGATION LONG TERM | FRESHWATER AQUATIC LIFE | | US AVERAGE CONCENTRATION | MONTANA | |
|---|---|---|---|---|---|---|---|---|
| | | | | effect | no effect | | AVERAGE | RANGE |
| Acidity as $CaCO_3$ | -[a126] | 170[a129] | | --[g40] | | | | |
| Alkalinity as $CaCO_3$ | --[d54] | 170[a129] | | --[g40] | | | 134 | 57-300. |
| Ammonia ($NH_3$) | .5[d55] | | | .11[d187] | .02[d187] | | | |
| Carbonate ($CO_3^=$) | 20[a155] | | | --[g40] | | | .11 | 0-13 |
| BiCarbonate ($HCO_3^-$) | 150[a146] | | 172[a146] | --[g40] | | 90[a147] | 158 | 61-500 |
| Carbon Dioxide ($CO_2$) | --[a156] | | | | --[d133] | | | 1.2-13 |
| Chloride ($Cl^-$) | 250[a161] | 1500[a161] | 100[a161] | | --[a161] | 9[a161] | 10.9 | <.5-74 |
| Cyanide (CN) | .01[d482] | | .2[k19] | .05[d190] | .005[d190] | | | |
| Fluoride ($F^-$) | 1.4-2.4[e] | 1.0[a191] | 1.0[d339] | 2.3[a191] | 1.5[a191] | | .43 | <.05-2.4 |
| Hardness as $CaCO_3$ | 150[g23] | | 70[a197] | | --[g141] | | 191 | 63-1260 |
| MBAS[3] | .5[d67] | | --[a199] | | | <.1[d190] | | <.01-17 |
| Nitrate ($NO_3$ as N) | 10[e] | 100[d316] | --[a225] | | | .9[a225] | .10 | <.01-.69 |
| Nitrite ($NO_2$ as N) | 1[d73] | 10[d315] | --[a226] | | | | <.01 | <.01-.02 |
| Oil and Grease | 0[g25] | 30[a231] | --[a231] | .39[g6] | | | | |
| Phenol ($C_6H_5OH$) | .001[a240] | 1000[a240] | 50[a240] | .079[d191] | | | | <.001-8.4 |
| Phosphate ($PO_4$ as P) | 50[a240] | | 60[a241] | | .01[m] | .087[d306] | .013 | <.001-.05 |
| PCB[4] | | | | .00001[d177] | .000002[d177] | | | |
| RSC[5] | | | 1.25 meq/l[h81] | | | | | |
| Silica ($SiO_2$) | 50[a258] | | 10-50[a255] | | --[a255] | | 8 | 1-32 |
| SAR[6] | | | 8[d335] | | | | 1.2 | .10-7.4 |
| Sulfate ($SO_4^=$) | 250[a276] | 500[a277] | 200[a277] | | --[a276] | 32[a276] | 130 | <10-1254 |
| Sulfide ($S^=$) | .2[a277] | | | .017[d193] | .002[d193] | | | |

# PESTICIDES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Endrin | .0002[e] | 4 mg/kg[f131] | | | $2\times10^{-6}$[d186] | | | |
| Lindane | .004[e] | 88 mg/kg[f138] | | | $2\times10^{-5}$[d186] | | | |
| Methoxychlor | .1[e] | 14 mg/kg[g131] | | | $5\times10^{-6}$[d186] | | | |
| Toxaphene | .005[e] | 4 mg/kg[f134] | --[a390] | | $1\times10^{-5}$[d186] | | | |
| DDT | .05[d77] | 35 mg/kg[f140] | --[a369] | | $2\times10^{-6}$[d186] | | | |
| DDE | | 880 mg/kg[f148] | | | | | | |
| 2,4,D | .1[e] | 20 mg/kg[f140] | 20[a366] | | 1.0[g37] | | | |
| 2,4,5,-TP Silvex | .01[e] | | | | 1.0[g37] | | | |
| Aldrin | .001[d77] | 5 mg/kg[f126] | | | $8\times10^{-7}$[g37] | | | |
| Dursban | | 82 mg/kg[f213] | | | $6\times10^{-5}$[g37] | | | |
| Fenthion (Baytex) | | 200 mg/kg[f214] | | | $6\times10^{-7}$[g37] | | | |

# EXPLANATIONS

.Letters and values following criteria indicate reference source and page number for criteria.
All values in mg/1 unless indicated.
< less than; no. following indicates detection limit of Montana State Water Lab using normal procedure with no extractic
*Indicates the minimum concentration of a substance for the use specified
1 TSS=Total Suspended Solids; 2 TDS=Total Dissolved Solids; 3 MBAS=Methylene Blue Active Substance;
4 PCB=Polychlorinated Biphenyls; 5 RSC=Residual Sodium Carbonate; 6 SAR=Sodium Adsorption Ratio
--no concentration limits set on the parameter reference and pg. no. given for prose discussion

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# SUMMARY OF WATER QUALITY CRITERIA

M. K. Botz and Dick Pedersen*

Values on this chart are concentrations that are not known to cause adverse environmental effects for the uses specified. The exception to this is the column which lists the lowest concentrations at which adverse biological effects have been observed for freshwater aquatic organisms. Superscript letters and numbers indicate the reference sources and page numbers for the criteria.

The chart shows average concentrations for the United States and the average and range of concentrations for Montana. The average concentrations for Montana are based on the three major rivers leaving Montana and the range is based on a review of typical data from 12 major streams in Montana.

Although concentrations on this chart are thought to be safe (except the adverse biological effect column), the effects of each substance depend on its interaction with other substances in solution. These effects can substantially enhance or reduce toxic effects when a combination of substances is present. For example, water hardness commonly influences the toxicity of many substances such as Be, Cd, Mo, Se, Zn. Substances in soft water typically are toxic in concentrations 5 to 75 times lower than in hard waters. Commonly, the hardness of water is not specified for toxicity tests; thus, no attempt was made to distinguish criteria for soft and hard waters. There is some information on the effects of hardness, however, and the chart user is referred to the referenced source. It also is important to recognize that these criteria are based on a limited amount of testing and additional testing may reveal adverse effects for some concentrations that are presently considered to be safe. The state of a substance also is important. For example, dissolved metals often are more toxic than are the same metals in a particulate state. Many bioassay tests do not report the physical-chemical state of the toxicant used. Where data are available for both suspended (particulate) and dissolved metals the dissolved concentrations were used.

Under aquatic life, the lowest concentration with no reported adverse effect is listed. Physical and chemical conditions and biological organisms tested can vary enormously; thus, the concentration listed may cause adverse effects under other conditions. Conversely, some organisms under some conditions may possible tolerate, without adverse effect, much higher concentrations of a substance than shown on this chart.

Also listed under aquatic life is a concentration at which an adverse effect was observed. A typical adverse effect is death of a portion of the test organisms. Commonly, fish are used for toxicity tests, but a wide variety of organisms can and have been used. Again, it is important to understand that concentrations less than those listed probably have adverse effects in many situations; however, with some organisms or other conditions, a higher concentration may not cause adverse effects.

Under aquatic life where effects are noted, the effect in all cases is mortality of the test organism. No attempt was made to list the mortality extent, organism involved, test period or other conditions. Chart users are referred to the referenced source.

Information and references used to compile this chart are listed and are probably the most commonly and widely used criteria. The search for suitable criteria was not extensive but was concentrated on those references thought to be the best overall criteria for waters in the United States.

Uses specified on this chart are the most common uses of water in most areas. Water quality requirements for recreation were considered since recreation is a common water use. It was found, however, that water suitable for other uses on this chart would be suitable for recreation. In cases where conflicting data from several sources were obtained concerning safe concentrations of a particular substance, the lowest concentration of that substance was selected.

Little or no criteria are available for some elements and their biological importance is poorly known. Elements not listed on this chart are:

Actinum (Ac)
Astatine (At)
Bismuth (Bi)
Cesium (Cs)
Dysprosium (Dy)
Erbium (Er)
Europium (Eu)
Francium (Fr)
Gadolinium (Gd)
Gallium (Ga)
Germanium (Ge)
Hafnium (Hf)
Holmium (Ho)

Indium (In)
Iridium (Ir)
Platinum (Pt)
Polonium (Po)
Praseodymium (Pr)
Promethium (Pm)
Protactinium (Pa)
Lutetium (Lu)
Neodymium (Nd)
Niobium (Nb)
Osmium (Os)
Rhenium (Re)

Rhodium (Rh)
Ruthenium (Ru)
Samarium (Sm)
Scandium (Sc)
Tantalum (Ta)
Technetium (Tc)
Tellurium (Te)
Terbium (Tb)
Thulium (Tm)
Wolfram (see Tungsten)
Ytterbium (Yb)
Yttrium (Y)

Headings used for this chart are somewhat inaccurate and were designed for convenience rather than scientific accuracy. For example, chloride ($Cl^-$) is listed as a compound whereas it is in fact typically an ion in solution. Similarly, hardness, SAR (sodium absorption ratio), and RSC (residual sodium carbonate) are not compounds but are conditions related to the water chemistry.

Mr. Tom Nickol, while a student at Carroll College in Helena, assisted in gathering much of the data shown on this chart.

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*Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena, Montana 59601; December, 1976.